BUILDING SCIENTIFIC LITERACY/(IES): A CROSS-CASE ANALYSIS OF HOW MULTIMODAL REPRESENTATIONS ARE USED TO MAKE MEANING DURING SCIENTIFIC INQUIRY

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

IN THE GRADUATE SCHOOL OF THE

TEXAS WOMAN'S UNIVERSITY

DEPARTMENT OF READING

COLLEGE OF PROFESSIONAL EDUCATION

BY

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DENTON, TEXAS

DECEMBER 2014

DEDICATION

This dissertation is dedicated to my mom and dad who inspired me to continue on with my education and to my grandparents who helped make the dream possible through their hard work and dedication.

ACKNOWLEDGEMENTS

I am truly indebted to the many individuals who have helped me to complete this chapter of my academic career successfully. My life has been deeply touched both on a personal and a professional level by the Reading and Literacy faculty members at Texas Women's University and the University of North Texas. I want to thank both my current and past committee members for their guidance and direction during this process--Dr. Nancy Anderson, Dr. Amy Burke, Dr. Connie Briggs, Dr. Nora White, Dr. Mariela Nunez-Janes, and Dr. Leslie Patterson. I have appreciated your continued support, dedication, feedback, and wisdom. Thank you for being a part of this journey with me.

I would especially like to express my deepest thanks and appreciation to my committee chairperson, Dr. Nancy Anderson, for her patience, understanding, and invaluable feedback. Both as a professor and as an advisor you have helped me to see and think in new ways. Your unwavering belief in me has helped me to believe in myself. I could not have successfully travelled down this road without you.

Many thanks must also be extended to my family members and friends who have stood by me during this long process--Kay Seward, Shawn Shannon, Shelly McMullin, Leslie Bukowski, Gary Love, John Shannon, Elizabeth Phillips, Donna Giles, and Brent Giles. Without your support and encouragement this dissertation would never have gotten done. I am thankful for each one of you!

And finally, I would like to thank the students who willingly chose to participate in this research study. I may be your "teacher," but you have taught me more than I can say. Thank you for opening my eyes and helping me to learn from you.

ABSTRACT

CHRISTA L. SHANNON

BUILDING SCIENTIFIC LITERACY/(IES): A CROSS-CASE ANALYSIS OF HOW MULTIMODAL REPRESENTATIONS ARE USED TO MAKE MEANING DURING SCIENTIFIC INQUIRY

DECEMBER 2014

This study used a Social Semiotic framework to describe the nature of multimodal textual representations created by fourth grade students in a small rural Texas school district south of Dallas in order to answer the question: What is the nature of the multimodal textual representations created by fourth grade students during the scientific inquiry process? Results of the cross case-analysis of the students' digitally recorded reflections, their multimodal representations, and my field notes and personal reflections as a teacher-researcher were indicative of five major themes. Representations created by the students: (a) were supported by scientific learning communities; (b) demonstrated varying abilities to collect both qualitative and quantitative observations; (c) utilized a variety of graphic organizers to communicate/represent scientific information; (d) were influenced by previous instruction and experience; and (e) showed development over time. These findings suggested the need for changes in the learning environment and pedagogy of science as teachers provide environments that support the development of

learning communities; provide multiple opportunities for students to make both qualitative and quantitative observations during scientific inquiry; provide explicit instruction into the semiotic tools used by professional scientists to communicate/represent meaning; and allow students the opportunity to reflect, critique, and discuss their representations so that they can learn to be more competent and fluent representors of scientific knowledge. Recommendations for future research included: learning more about the way learning communities scaffold the learning process during scientific inquiry; understanding the best practices for helping students to learn how to make qualitative and quantitative observations of the world around them; describing the best practices for teaching students to be multimodal designers of scientific knowledge; examining the effect of previous instruction on the multimodal representations created by students; and learning more about how to best develop the students representational competency in science.

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CHAPTER I

INTRODUCTION

Overview

New literacies of the twenty-first century are shaping the ways people make sense of and interact with the world around them (Lankshear & Knobel, 2006). Our once print-dominated communication world is gradually shifting to integrate a variety of other semiotic, or meaning-making, systems. Visual images are quickly gaining prominence and are finding their way into our everyday literacy usage as well as into the classroom (Bezemer & Kress, 2010; Bearne & Wolstencroft, 2007; Kress, 2004). As a result, the impact on thinking and making sense through the use of these various modes of communication is gradually expanding what it means to be literate. The effect of this shift in our understanding of literacy causes us to examine how we define a "text;" the process one uses to make sense of a given text (or to comprehend the texts' intended message); and how one uses various semiotic, or meaning-making, resources to construct these messages. As the definition of literacy continues to evolve, teachers will have to rethink their traditional pedagogical practices that are geared toward teaching students how to make sense from print-dominated systems and give them the opportunities needed to understand and create meaning in this "multi-semiotic environment" (Morgan & Alshwaikh, 2010). This need has been and will continue to be especially true in the discipline of science.

As a discipline, science has its own Discourse, or unique way of making, representing, and communicating meaning (Gee, 1990). As part of the professional Discourse of science, scientists have often used multimodal representations to communicate and express their conceptual understandings. Multimodal representations may be understood to be any expression of meaning that utilizes more than one semiotic, or meaning-making, resource (whether it be written, verbal, mathematical, visual, graphical, etc.) (Prain & Waldrip, 2006). Often, the discipline of science requires more than one semiotic mode, or meaning-making tool, to meet the communicative demands of the subject area (Lemke, 1998). Diagrams, data tables, graphs, and mathematical equations are often used in conjunction with verbal expressions to help express scientific concepts and understandings. Being able to competently represent and communicate these scientific ideas using multiple semiotic resources is seen as a necessary skill for participating in the Discourse of science on multiple levels.

Recent trends within the development of both national and state science education standards for grades K-12 have supported this growing emphasis. The development of the national science standards for science education, or what are known as the *Next Generation Science Standards (NGSS)*, have shown that students need to understand the concepts skills/processes associated with the field of science being studied to become fluent in the literacy demands of the subject area itself (NGSS Lead States, 2013). The state of Texas has also indicated the importance of the role of these multimodal literacy skills by including them in their Texas Essential Knowledge and Skills found in the Texas Administrative Code (19 Tex. Admin. Code § 112.15 (b) (1-4), 2010). This is discussed further in the literature review.

This Teacher-Action Research (TAR) project sought to provide a description of the nature of these multimodal representations of meaning-making by conducting a cross-case analysis of the multimodal representations created by sixteen fourth grade students in a rural town in Texas. This study described how these multimodal representations were indicative of the students' participation in the larger Discourse of science. It also examined how students were creating meaning as they constructed these multimodal representations during the scientific inquiry process and looked at how they described the nature of the textual representation themselves.

Problem

Creating multimodal representations in science is an integral part of the scientific inquiry process and is essential for participating in the Discourse of science. Students must be able to represent and re-represent scientific concepts and understandings in various modes in order to communicate to and be part of a larger scientific community.

Current research has supported the connection between representations and the development of scientific concepts (Prain & Tytler, 2012; Tytler, Peterson, & Prain, 2006) and has shown the importance of the role the teacher plays in how students interpret and create multimodal representations (Gerstner & Bogner, 2009). Yet, no studies found in the scope of the literature reviewed for this research study have been conducted by teacher researchers in order to describe the nature of these multimodal representations or to explain how the students are using these multimodal representations to create meaning for themselves during the process of scientific inquiry.

Insight gained from such a study would help further develop a meta-language for describing the features of multimodal representations (diSessa, 2004) and would help empower educators to teach children how to represent and re-represent these scientific concepts across various modes. Teachers must understand both the nature of multimodal representations and the meaning that the students are making during the process of creating representations of scientific concepts in order to develop the best practices for equipping students to be competent, fluent designers of multimodal representations.

Purpose of Study

The purpose of this study was to utilize a Social Semiotic perspective of meaning-making to provide a cross-case analysis of sixteen fourth-grade students in order to describe the nature of the multimodal representations created by these students as part of the scientific inquiry process. A Social Semiotic perspective views meaning-making as a social process where members of a set community, or Discourse, use a variety of meaning-making resources, or modes, to communicate/represent an intended message (Halliday, 1978; Hodge and Kress, 1979; Gee, 1990). These semiotic resources, or modes of meaning-making, may be visual, auditory, written, graphical, etc. Any social tool used to make meaning can be considered a semiotic resource (Halliday, 1978;

Lemke, 1990). In this research, multimodal representations, or texts, were defined as a combination of semiotic modes (written, verbal, mathematical, visual, graphical, etc.) used to independently and/or cooperatively communicate or represent a message or understanding of a scientific concept (Prain & Waldrip, 2006). The analysis provided by this research specifically showed how the multimodal representations generated by these fourth grade students were indicative of their participation in a larger scientific Discourse. This research also showed how the students were creating meaning while they were creating their multimodal representations. Finally, this study described the nature of the actual multimodal representations created by the sixteen fourth-grade students during the inquiry process.

Theoretical Framework

In the last few decades, reliance on traditional print-based modes of communication have declined and greater emphasis has been placed on digital and multimodal forms of communication (Bezemer & Kress, 2010; Bearne & Wolstencroft, 2008; Kress, 2004). Although science as a discipline has always been multimodal, this paradigmatic shift has still directly impacted the teaching and learning of science. Today, more than ever, science education must draw on a multitude of semiotic, or meaning-making, resources to interpret and communicate scientific meanings. Several theories have developed over time in response to the ever-changing modality of today's communication landscape. Two of these theories have been significant in guiding the decisions made during the course of this teacher action research project: multimodality and Social Semiotics. These theories provided a framework from which to interpret and understand how multimodal representations are used by elementary students during scientific inquiry.

Multimodality

The first of these theoretical approaches used to provide a framework for understanding how multimodal representations were being used in science inquiry comes from work done in the area of multimodality. Multimodality developed in response to the many paradigmatic changes in communication and representation over the last few decades (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Kress & van Leeuwen, 2001).

In his book *Reading Images: Multimodality, representation, and new media.* Guther Kress (2004), and later Bezemer and Kress (2010), have acknowledged this growing shift from the medium of the printed page to that of digital media and the questions that such a shift brings forth. According to Kress (2004), in order to address the newer multimodal communication and representation environments paramount to this shift, one must be able to understand the role choice and design play in creating meaning. Many messages are now relying less on printed words in light of other semiotic resources available. One such example of this is the growing reliance on images to communicate or convey meaning to a given audience. With the digital screen and other advanced technology mediums available, many images are replacing words as the central mode of communication (Bezemer & Kress, 2010).

Multimodality requires designers and audiences alike to understand the expansion of rhetorical devices being used by designers of these communicative efforts. Each alternative mode of meaning-making, or semiotic resource, has its own inherent set of rhetorical devices that must be understood. Such work on visual images has been done by Claire Harrison (2003). One of the main advantages of a multimodal approach is that it provides a lens for beginning to understand these rhetorical capabilities and how these design selections influence the meaning being constructed.

A multimodal approach provides a foundation for establishing research methodologies and analytical frameworks for addressing textual representations that incorporate multiple semiotic resources (Bezemer & Jewitt, 2010). These semiotic resources may include visual elements, design elements, written elements, and other semiotic resources (Jewitt, Kress, Ogborn, and Tsatsarelis, 2001). According to Bezemer and Jewitt (2010), the underlying assumptions guiding a multimodal approach to meaning-making include three key understandings: (a) that meaning is communicated through multiple semiotic resources, (b) that meanings are socially constructed and are shaped by the social community that one is part of, (c) and that people strategically utilize various modes in significant ways to communicate or represent meaning in particular ways.

A multimodal approach has also contributed to educational and other social research in several other ways. Bezemer and Jewitt (2010) assert that research in multimodality has focused specifically on describing the modes and semiotic resources being used to communicate/represent meaning and that it has provided insight into how various modes and semiotic resources interact and can be interpreted in various digital landscapes. In addition, research guided by multimodality has been able to identify new digital semiotic resources currently in use (Bezemer & Jewitt, 2010). Multimodality has also helped guide researchers in the collection and analysis of multimodal texts, especially in digital environments (Jewitt, 2010).

As presented above, a multimodality approach does provide a unique framework from which to interpret and analyze multimodal textual representations and it has begun to provide researchers with a base from which to make methodological and data analysis decisions. Its strengths, however, seem to best describe digital mediums and more work is needed to expand its ability to address all types of mediums used to create multimodal textual representations. Its current applicability to classroom use also appears to be limited, especially in areas where access to technology is still limited, or where it has just been introduced.

Further research and development of a rhetoric for each semiotic resource is also needed in order to enhance a multimodal approach. An understanding of how rhetoric might change when semiotic resources are utilized together still seem to be needed. Even in view of the much needed work and current limitations in the field, multimodality still serves to provide one of the most valuable lenses from which to analyze multimodal representations.

Social Semiotics

The theory of Social Semiotics allows viewers of multimodal textual representations to take their analysis even further by looking at the socially constructed sign systems used by people to communicate meaning. Within a Social Semiotic account of meaning-making, meaning is communicated through socially mediated "signs." These signs are created using various semiotic resources available within the social community that are available for the purpose of making meaning. Each semiotic resource, or mode, has certain affordances or limitations inherent in its communicative ability (Bezemer & Kress, 2010). Because this view of communication and meaning-making relies on a particular social community's ability to understand the sign being produced, meaning can be understood as a socially, culturally, and historically mediated construct (Bezemer & Jewitt, 2010). According to Bezemer and Jewitt (2010), other guiding theoretical assumptions of Social Semiotics include: (a) an understanding that meaning is communicated/represented multimodaly and that each mode contributes to the overall meaning; (b) various modes or semiotic resources are used to make-meaning in different contexts and are organized according to the needs of that particular occasion or as appropriate for the specific communicative purpose; and (c) the interaction of these modes work together to produce meaning. The theoretical ground work for these assumptions come from the seminal works of theorists such as Michael Halliday (1978), Kress and van Leeuwen (1996, 2006), and Hodge and Kress (1998).

Much of the Social Semiotic approach is hinged on two foundational approaches. The first of these is Michael Halliday's Systemic Functional Analysis (SFL) which provides a basis for the kinds of meaning created by three "metafunctions" of language: the ideational, the interpersonal, and the textual level (Halliday, 1978). A second theory part of the development of Social Semiotics arises from the work of Kress and Van Leeuwen (1996). Their seminal text, *Reading Images: The Grammar of Visual Design* (1996, 2006), which provided in-depth information on visual design has provided a basis from which to interpret and understand visual images and multimodal texts by looking at their composition, the perspective they provide, and their use of visual symbols. Hodge's and Kress's work, *Social Semiotics* (1998) has also significantly contributed to the development of this field and has helped to construct the idea of semiotic systems for meaning making. These semiotic systems are the tools/resources people use to make meaning within a given community (Harrison, 2003). Many others (see also Jewitt & Oyama, 2001; Harrison, 2003; Bezemer & Kress, 2010; Bezemer & Jewitt, 2010; and Serafini, 2011) have also continued to utilize and contribute to the current understanding of Social Semiotics.

Social Semiotics offers many strengths to researchers looking at multimodal texts and often works in close connection to theories of multimodality. It provides a social lens from which to approach meaning-making and looks at the resources used to create meaning as social constructs as well. As such, it is often provides a theoretical lens that allows researchers to understand multimodality from a social perspective and is the perfect lens for analyzing how these textual representations may reflect the larger Discourse of science.

Research Question

During the course of this Teacher-Action Research project, a cross-case analysis was used to address the following research question:

> What is the nature of multimodal textual representations created by fourth grade students during the scientific inquiry process?

Significance of the Study

This study on the nature of multimodal textual representations and meaning-making during scientific inquiry is important because it fills a gap in the currently available literature on multimodal meaning-making in science. It also directly informs practice, and helps guide future research and policy development.

An important part of this study's significance is its ability to contribute to the scholarly research currently available both in the fields of multimodality and in scientific inquiry and pedagogy. This study aimed to do this by providing a rich description of the nature of multimodal representations currently being used by students during the inquiry process. This description is vital in helping us to understand what students already know and in continuing the process of developing a meta-language for multimodal representations so that we can understand and discuss what it means to be competent or fluent in our ability to represent meaning multimodaly and then how this differs by discipline. It also allows us to see how instruction in multimodal text construction is connected to teaching students how to participate in the Discourse of science and how it is connected to building their identities as scientists. Multimodal text instruction is part of apprenticing students into the scientific Discourse and therefore it must be a priority. Specifically, this research provided a description of the literacies of science currently being practiced by the fourth grade students participating in this study and their peers in the school district where this study was conducted.

As an extension of these understandings, this study was also instrumental in helping to improve science pedagogy. Understanding what my students currently know and to what degree they know it will help guide future instructional decisions as I seek to provide inquiry opportunities that will develop not only my students' conceptual knowledge of science, but also their knowledge of the literacies of science, both of which are important in helping my students learn about the larger Discourse of science. It also opens the door to future and on-going conversations with my students about how scientists make and represent meaning. This study provided a point of access for developing a personalized meta-language with my students that allowed and will continue to allow us to work together, as scientists, to make decisions about how to better represent or communicate our scientific understandings in ways that are recognized by the larger scientific Discourse. In doing so, both the students, and myself included, will be further apprenticed into the art and practice of participating in the Discourse of science (Gee, 1990). This study helped guide our understanding of how to both design and consume multimodal scientific representations and the tools that are available to continue building our multimodal literacy skills.

A final contribution of this study was its ability to inform future research and policy within the field of science education. As part of the literature review for this study, it was evident that further research is still needed to understand how to teach multimodal literacy skills as part of a larger science pedagogy. A few studies have already indicated that teachers often have misconceptions about how well their students are able to comprehend visual images in science textbooks (Prain & Waldrip, 2006). Without direct observation, teachers may not be fully aware of what literacy practices their students currently are able to use and/or how to provide meaningful opportunities for their students to develop their skills of interpreting, designing, and evaluating multimodal representations in science. Teachers need to address their current misconceptions about literacy and literacy practices within their field of practice in order to provide better instruction. As teachers develop a broader, modal view of literacy, they will need to be equipped to help their students to become designers of representations that reflect this understanding. For this to happen, curriculum standards and research practices must continue to reinforce this shift in literacy practices. As such advances are made, a more complete picture of what it means to be representationally competent and fluent will evolve. This study demonstrated that much work in these areas is still needing to be done.

Definition of Terms

This section provides a brief overview of how each of the following terms were defined for this study.

Discourse(s)/discourse of Science

Discourses with a "big D" was first distinguished by James Gee (1990) to represent the way one may engage in a social group by talking, acting, feeling/valuing, and believing that allow him/her to "belong" to a particular social group. Members of a particular Discourse are often "apprenticed" into the community of practice by others who know how to talk, act, feel/value, and believe as a part of that social group/community.

In science, students are "apprenticed" into the ways that scientists talk, act, feel/value, and believe. They must learn how to make-meaning in the same ways that other scientists do.

Multimodal Representations/Semiotic Modes

In this research, multimodal representations or texts were defined as a combination of semiotic modes (written, verbal, mathematical, visual, graphical, etc.) used to independently and/or cooperatively communicate or represent a message or understanding of a scientific concept (Prain & Waldrip, 2006)

Semiotic Resources

Any resources used to make meaning was considered a semiotic resource (Halliday, 1978; Lemke, 1990). Semiotic resources may include language, gestures, drawings/graphics, mathematical expressions, dance, etc. Semiotic resources can be used individually or in conjunction with other resources/modes to make meaning.

Literacies of Science

The literacies of science were defined as all of the ways that scientists communicate and make meaning while participating in the Discourse of science. It includes the way they describe, compare, classify, discuss, analyze, evaluate, follow procedures, design investigations, report, write, and communicate scientific understanding (Lemke, 1990).

Representational Competency

According to diSessa (2004), representational competency includes a student's ability to construct, explain, evaluate, and critique the quality of various multimodal representations.

Representational Fluency

Representational fluency is the ability to translate (represent and re-represent) meaning across various modes and representations. It has been identified as a key factor in building scientific literacy (Prain & Waldrip, 2006; Bezemer & Kress 2010).

Scientific Literacy

The national committee that has developed the *Next Generation Science Standards* for K-12 science education defines science beyond a set of facts to be learned. It consists of the knowledge of evidence-based scientific concepts, the building of models and theories, and the process of continuously extending, refining, and revising that knowledge based on new evidence. The *Next Generation Science Standards* are divided into three domains: practices (which includes the knowledge and skills, or set of processes, scientists engage to develop and critique models and theories); cross-cutting concepts (the concepts that help link scientific ideas together and help develop a scientific world view that can identify patterns, cause and effect, scale, structure and functions, or stability and change to name a few); and disciplinary core ideas (the scientific concepts in each major discipline of science) (NGSS Lead States, 2013). The scientific practices identified in the national science standards, NGSS, listed above require student scientists today to understand the multimodal nature of the meaning-making practices of a scientific Discourse to be considered scientifically literate.

Summary

Scientific literacy today requires students to be able to construct and evaluate multimodal representations in science. As a result, science teachers and classrooms must be equipped with the appropriate tools necessary to help students learn how to represent and re-represent scientific understandings using the literacies of science. In order to do so, teachers must first understand what students know about constructing multimodal representations. This teacher action research project sought to describe the nature of sixteen multimodal representations created by fourth grade students as part of the inquiry process. A cross-case analysis of these representations described how these representations were indicative of the students' participation in the larger Discourse of science, how the students were making-meaning during the construction process, and the semiotic tools that were being used to construct these representations.

CHAPTER II

REVIEW OF LITERATURE

Overview and Purpose

Scientific inquiry allows students to explore and understand the natural world around them in deeper ways through direct observation and measurement. As students learn to engage in the skills and processes necessary for them to "be" scientists (Gee, 1990; Lemke, 1990), they must also learn how to communicate their understandings and findings in ways that allow them to more fully participate in the larger scientific community. This development of a student's "literacies of science" are an essential part of "doing science" today (Lemke, 1990). Specifically, this review identified current theoretical and empirical research related to multimodal representations, to meaning-making during scientific inquiry, and to how these two concepts intersect and were connected in ways that help student's build their scientific literacy.

For the purpose of this review, multimodal representations or texts were defined as a combination of semiotic modes (written, verbal, mathematical, visual, graphical, etc.) used to independently and/or cooperatively communicate or represent a message or understanding of a scientific concept (Prain & Waldrip, 2006). Meaning-making was used to describe how members of a community "perform actions that are meaningful in the community." These meaning-making practices were also referred to as "semiotic practices" (Lemke, 1990). Scientific inquiry referred to the processes of "observing, describing, comparing, classifying, analyzing, discussing, hypothesizing, theorizing, questioning, challenging, arguing, designing experiments, following procedures, judging, evaluating, deciding, concluding, generalizing, reporting, writing, lecturing, and teaching in and through the language of science"; what Lemke (1990, p. 1) calls "talking science."

This review of theoretical and empirical literature sought to describe what is currently known about the nature of multimodal representations and the meaning children are making during scientific inquiry. This allowed me to better understand the meaning my students were constructing as they created multimodal representations during the inquiry process and in doing so will eventually allow me to find ways to help them further develop their ability to communicate/represent their scientific understanding using the literacies of science.

The purpose of this literature review was to provide a critical analysis of the most pertinent theoretical and empirical research currently available pertaining to how multimodal representations are used during scientific inquiry to make meaning and build scientific literacy and to identify the gap in the literature that will lead to future scholarly research in this field. In order to do that, this literature review described:

1. The salient features of multimodal representations identified in research.

2. How multimodal representations are currently used and understood by teachers and students in the classroom.
3. The role of multimodal representations during scientific inquiry and how they contribute to meaning-making.
4. How multimodal representations support meaning-making during scientific inquiry.

Organization of Review

A literature map (Figure 1) was created to guide the search, selection, and discussion of the literature used in this review. In seeking to understand what is currently known in the theoretical and empirical literature about the nature of multimodal representations and meaning-making during scientific inquiry, the review focused on three main areas: literature describing multimodal representations, research done on meaning-making during scientific inquiry, and findings pertaining to multimodal representations and meaning-making during scientific inquiry.

The first section on multimodal representations introduces the paradigmatic shift from traditional print-based modes of communication to the current multimodal environment. It also identifies key features of multimodal representations found in the research and discusses how both this paradigmatic shift and the multimodal texts themselves are being incorporated into pedagogical practices. The second part of this review then looks at how students are engaged in meaning-making practices during scientific inquiry. This section focuses primarily on how conceptual understandings and misconceptions are identified during inquiry and how meaning-making is connected to the development of a student's scientific literacy. The final section looks at the literature available on the role of multimodal representations created during scientific inquiry and in the development of representational competency and fluency as well as identifies the needs for future research in this area.

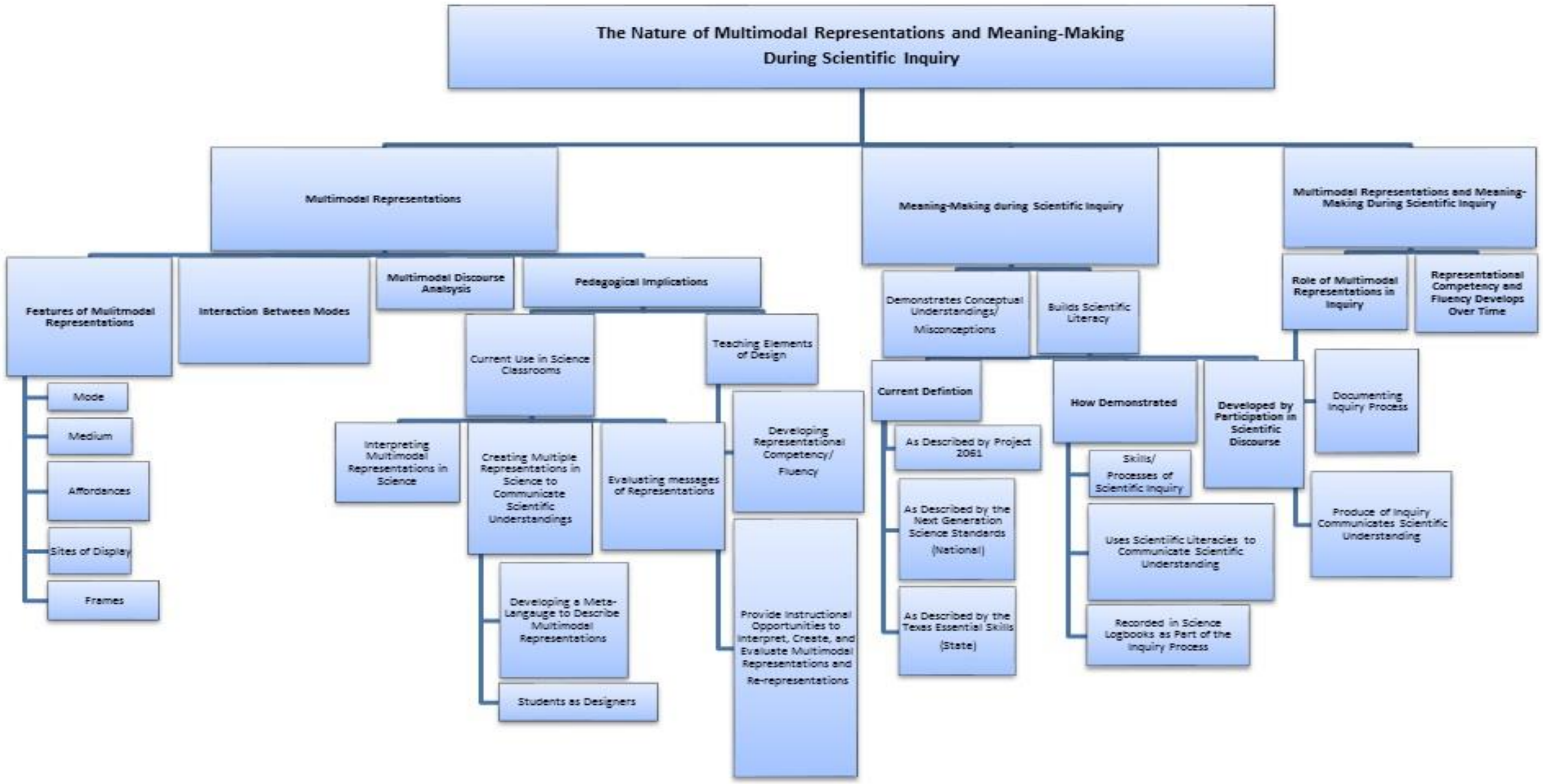


Figure 1: Literature map

Scope and Context

This literature review provides a representative picture of the most recent theoretical and empirical literature pertaining to multimodal representations and meaning-making for students of all ages. Emphasis was placed on finding selected literature that approached the topic of multimodality and meaning-making in science from a Social Semiotic framework. Due to the static nature of the text medium being analyzed in this study, some data that referred explicitly to computer-based mediums or programs used for multimodal analysis of digital mediums were excluded. Most of the literature included in this review has been published since the year 2000 unless it was a seminal work or a work pertinent to the scope of this inquiry. Publications for this review have been selected primarily from the disciplines of education, communications, and literacy, and were selected from journals, books, and selected chapters for relevant books published both in the United States and Australia.

Research Plan and Strategy

The initial search for literature for this review was conducted on databases provided by the Texas Woman's Library website including: Academic Search Complete, EBSCOhost databases, ebrary, and through Dissertation Abstracts Online & ProQuest Digital Dissertations. A few print-based publications were located by searching the library's digital catalog. Search terms used to identify literature included multimodality, multimodality in science, multimodal meaning-making, multimodal representations, multimodal representations in science, multimodality and scientific inquiry, scientific inquiry, and representational competency. A snowball method was also employed to identify other significant works for this review and a few book chapters were provided by my academic chair person. Further articles and sources were identified from citations while reading the articles for the review. Literature reviewed included peer-reviewed journal articles, scholarly publications, book chapters, and seminal works (both in article and book form).

Interest, Significance, and Rationale for Critical Analysis

The timeliness of the topic being addressed in this review makes it of interest to researchers and practioners alike. The paradigmatic shift from a print-based communication system to a multimodal communication landscape continues to bring challenges for teachers and students alike. Understanding what is known about multimodal representations and how they are used to make meaning during scientific inquiry helps improve science instruction and allows teachers to better equip students to both interpret and design multimodal texts that are able to communicate scientific understandings. This topic is also of great personal interest as it helps me to reflect on my current teaching practices and provide future instruction that will strengthen my students' ability to participate in the Discourse of science by equipping them to more effectively use the literacies of science. The following section provides the review of literature for this topic and concludes with a recommendations for future scholarly research in the area of multimodal representations and meaning-making in scientific inquiry.

Review of Literature

Following the literature map, the first section of this literature review begins by looking at how the current research has delineated the key features of multimodal representations; provides a brief overview of the interaction between various semiotic modes as described in the research; discusses current developments in methodologies to analyze multimodal texts (Multimodal Discourse Analysis); and discusses how multimodal representations are currently being addressed in educational pedagogy.

Features of Multimodal Representations

One key contribution of Social Semiotics has been its ability to help identify the key features of multimodal representations. Essential features designated in current literature from a Social Semiotic approach have identified the importance of mode, medium, affordances, sites of display, and frames as essential elements in designing a multimodal textual representation.

Modes of communication are at the heart of a multimodal text. According to Kress (2004), modes can be written expressions or visual images (see also Thompson, 2008, O'Halloran & Smith, 1999-2014). Other modes may include moving images/action (Bearne & Wolstencroft, 2007; O'Halloran & Smith, 1999-2014), gestures (Thompson, 2008; O'Halloran, 2011), scientific symbolism (O'Halloran & Smith 1999-2014) and sound/auditory (Bearne & Wolstencroft, 2007; Thompson, 2008; O'Halloran & Smith 1999-2014). Each mode is a social, cultural, and historical construct purposefully chosen by a person to communicate an intended meaning to a specific audience/community (Bezemer & Kress, 2010). Designers of multimodal texts, use these semiotic resources, for very specific rhetorical purposes (Harrison, 2003). The choice of mode requires a designer to make certain choices about meaning, whether it is an intentional design choice or one that happens unintentionally (Kress, 2004). Multimodal texts use these semiotic resources, or modes, to construct a message for a particular social community. The process of designing a multimodal representation must take into consideration the choice of mode and what that mode is able, and is not able to communicate to a given audience (Kress, 2004). This design choice is influenced highly by interest and appeal as well as how a designer wishes to position him/herself in relation to the intended audience (Kress, 2004).

Each mode is also afforded particular meanings or limitations of meanings based on the medium that is chosen to communicate or display the intended message. The medium chosen may be print, digital, aural, or embodied by an individual depending on the mode being used. It is chosen by the designer in conjunction with the choice of mode to create/design a message. When choosing a medium, designers must take into account their audience's preferences, their own individual preferences, and how such a design choice will position them and their audience (Kress, 2004). In recent decades, the shift in medium from print to screen has significantly influenced the design decisions being made (Kress, 2004).

As briefly mentioned previously, each mode and medium used to communicate meaning provides certain advantages and limitations to its ability to communicate. These advantages and/or potentials and their associated limitations make up what Social Semioticians have described as the "affordances" of a mode (Kress, 2004; Bearne & Wolstencroft, 2007).

A site of display, describes the way that a designer chooses to present the multimodal textual representation. A site of display could include a stage, a poster, a booklet, a flier, a website, a movie screen, etc. (Bezemer & Kress, 2010).

A final feature of multimodal textual representations noted in literature and of significance in this review is that of frames. Framing refers to the ability of each mode to establish boundaries. In written language a frame can be represented by punctuation which signals to the intended audience where thoughts start and stop (Bezemer and Kress, 2010). Other signifiers of meaning can be used to provide this social frame in other semiotic resources. Framing helps communicate meaning to the intended audience within a particular mode of communication.

As noted above, understanding the key features of multimodal textual representations helps provide a groundwork from which multimodal textual representations can be understood, described, and analyzed. Without such a meta-language, instruction and research in the area of multimodality would not be possible.

Interaction between modes. Social Semiotics has also directly influenced our current understanding of how meaning is communicated by the interactions between the various modes utilized within a multimodal texts. As mentioned above, Social Semiotics assumes that: (a) meaning is communicated/represented multimodality and that each mode contributes to the overall meaning; (b) various modes or semiotic resources are used to make-meaning in different contexts and are organized differently for different purposes; and (c) the interaction of these modes work together to produce meaning (Bezemer & Jewitt, 2010). As such it is important to briefly discuss the current literature available pertaining to the meaning created via the interaction between various modes in a multimodal text.

Many researchers looking at the interaction of modes have focused their research on the "modality principle" (Moreno & Mayer 2002; Mayer, Hegarty, Mayer, & Campbell, 2005; Harskamp, Mayer, & Suhre, 2007; Eliam & Poyas, 2008). This principle looks specifically at which modes best support a student's learning in a multimedia environment. Many of the studies, incorporate a variety of qualitative and quantitative data to examine learning with words only, learning with words and auditory support, or learning with auditory and visual support (see Moreno & Mayer, 2000; Moreno & Valadez, 2005; Harskamp, Mayer, Suhre, 2007; Elias and Poyas, 2008). Such studies have found that student learning is improved when student instruction includes written, verbal, and visual modes (Moreno & Mayer, 2000; Harskamp, Mayer, Suhre, 2007; Elias and Poyas, 2008). A study conducted by Mayer et al (2005), sought to understand how student learning might be affected by digital versus print media as well. Results from this study indicated that students are required to engage in less "extraneous processing" and more "germane processing" when given print-based texts as opposed to digital texts with narration and animations. Another study indicating that additional modes may increase the amount of processing required by a student and therefore interfere with comprehension was conducted by Moreno and Valadez (2005). In this study, researchers found that college age students who were instructed with a multimedia presentation incorporating words and pictures were able to achieve the highest levels of information retention and transfer, but when having to also organize the multimedia materials as part of the task, transfer declined due to the cognitive load.

Other significant studies in this area also focused on the image-text relationship within multimodal texts. One such study was conducted by Daly and Unsworth (2011) as part of a larger research project in partnership with the Australian Research Council. Their research found that image and text can work together to support student comprehension. When students are unable to decode multimodal texts it may be due to their difficulty to decode one particular mode rather than a lack of ability to understand the image-text relationship. Wiebe and Anetta (2008), also conducted research in the area of text-image interactions, but instead focused on how the two are integrated and how comprehension of a text can be supported by narration.

It is important to note that the data provided by the studies above provide a mixed view of the effectiveness of multimodal textual representations in promoting student learning. Further research is needed to identify if the limitations of multimodal support is the effect of the multiple modes being used or is if it is indeed the result of the increased cognitive load of the task and whether or not these are mutually exclusive.

The research in this area is yet limited in its scope as well. Much of the research provided focuses on a multimedia environment. Further research is necessary to determine if similar results are seen when using various mediums and in seeing if the same is true when students themselves are employed as the designers of these texts as opposed to the consumers.

Multimodal Discourse Analysis. As researchers continue their efforts in understanding the interpretation and construction of multimodal textual representations, they must be equipped with methodologies that can address the unique demands of multimodal texts. Although, many researchers have incorporated a variety of qualitative and quantitative research methodologies, one common theme in the area of methodology that has arisen is that of Multimodal Discourse Analysis (MDA). Multimodal Discourse Analysis has built on the work of Social Semiotics and seeks to provide a set of tools to analyze which modes are chosen to communicate meaning, how these choices are made, and the relationship between the modes within the text itself. This level of analysis also seeks to understand how these texts are constructed, produced, and shared within a social setting (O'Halloran & Smith, 1999-2014). Multimodal Discourse Analysis is still in its infancy, but seeks to expand current practices in Discourse Analysis to other semiotic modes to understand how these work together to create meaning.

Pedagogical implications. The paradigmatic shift from print to screen has not been escaped by schools. The demands of this multimodal communication landscape are requiring students to develop new literacy skills. Students must be able to comprehend and construct multimodal texts. This section of the literature review provides an overview of the literature available on how multimodal representations are currently in use in science classrooms today and the role teachers play in equipping students to handle the literacy skills that will be required of them in the twenty-first century.

Students in today's classrooms, especially in science classrooms, must be able to interpret, construct, and evaluate multimodal representations. Multimodal representations within the science classroom are often heavily laden with visual images that require a student to employ unique sets of comprehension strategies that will enable them to decode these visual images. Many researchers have identified the challenges students face when trying to interpret visual images (see Amettler and Pinto, 2002).

Teachers working with these students often have many misconceptions about their students' ability to interpret visual images. Research, however, has found that comprehension is supported when teachers specifically directly teach or draw attention to the visual elements within a text (Lowe, 2000; Amettler & Pinto, 2002; Stylianidou, Ormerod, & Ogborn, 2002; Leewalter, 2003; Chittleborough and Treagust, 2008; Coleman, Bradley, & Donovan, 2012). McTigue and Flowers (2011) conducted an exploratory study that revealed that difficulty understanding visual images, or specifically diagrams, were caused by three main things: (a) the difficulty or grade level of the diagram, (b) the attractiveness of the diagram, and (c) the diagram's utility in communicating the scientific concept. The relationship between these various semiotic modes is much more complex than teachers often realize (Barnford, 2003; Kong, 2006).

Research has shown that teachers need to specifically point out the role visual images play in a text. Coleman, Bradley, and Donovan's (2012) study with second grade children shows how this can be done. In this study teachers used read-alouds to draw attention to the visual elements incorporated into a non-fiction multimodal text on weather. As children discussed the various visual elements used by the illustrator, the teacher led the children in creating a chart of the visuals they had encountered while reading the multimodal text. Strategies such as this allow students to develop the comprehension strategies that they need to move beyond traditional text-based comprehension strategies and to understand multimodal texts. Serafini (2011) refers to this as "expanding" the "students' interpretive repertoires."

Much of the current research available on how students are creating meaning from multimodal texts in science relies heavily on interpreting the visual images of scientific text. Although, this type of research is essential to building the body of research available, much more work is needed to understand how to help our kids interpret other semiotic resources as well. Perhaps similar types of pedagogical activities, that model and explicitly teach how semiotic resources are used to create meaning in science, can be employed for all of the various semiotic resources. As part of their participation in scientific inquiry, students must be able to not only interpret multimodal texts, but also create them in ways that communicate scientific understanding.

Visual representations are based on observations made during the scientific inquiry process. Students use the representations of their observations to layout and represent the relationships between the objects being observed (Hanauer, 2006). Brooks (2009), found that when students were allowed to use drawings to aid their visualization of scientific concepts that their development of understanding complex scientific ideas was supported. As students attempt to represent their observations or scientific understanding, they face multiple challenges. These challenges include knowing how to competently represent their understanding by making design choices that integrate various modes of representations. Students need multiple opportunities to practice constructing and justifying their representations (Waldrip, Prain, & Carolan 2010). Other research has found that different students have different ways of "seeing" and thus "representing" the natural world. Although these alternative ways of "seeing" may be indicative of misconceptions, they may also need to be recognized as valid alternative representations (Reiss, Boulter, & Tunnivliffe, 2007).

An Australian study conducted by Tytler, Peterson, and Prain (2006), looked at how students represented the process of evaporation and the challenges they faced when doing so. Using a qualitative methodology involving an analysis of multimodal representations created by students and transcripts of student accounts of their thinking, Tytler, Peterson, and Prain (2006) discovered that representations can be used as thinking tools. The scientific ideas being represented are directly connected to the students' ideas about science. Learning occurs as students evaluate their representations, engage in talk about their representations, and make adjustments to represent or re-represent the concept (see also Brooks, 2009). This research gives strong evidence that researchers and practioners alike must recognize that representations and conceptual understanding are interconnected. It also provides a strong argument for providing "representational-rich environments" in the science classroom. Such practices are key to helping students develop their abilities to communicate using the literacies of science (Tytler, Peterson, & Prain, 2006). Further studies conducted by Prain and Tytler (2012) continue to support the thesis that creating multimodal textual representations provide students with opportunities for students to develop their conceptual understanding. As part of their most recent efforts, Prain and Tytler (2012) have developed a framework to demonstrate how students learn from creating multimodal representations. This framework is known as the *Representational Construction Affordances Framework*. Three main components of this framework include the semiotic, epistemic, and epistemological perspectives. The semiotic perspective focuses specially on understanding the semiotic resources used by students to construct their text. The epistemic perspective looks at how the choice of semiotic resources helps the student build scientific knowledge during scientific inquiry. And, the epistemological perspective focuses on what can be known through various representations.

Student-generated multimodal textual representations have also been connected to high levels of student engagement (Prain & Tytler, 2012). Part of engaging students in the process of generating multimodal texts is teaching them a meta-language that equips them to talk about the elements of design.

If students are to become competent designers of multi-modal texts they must have a language to talk about multimodal texts and the associated design principles. On the forefront of this development is the work of diSessa (2004). DiSessa (2004) developed a meta-representational competence to help discuss the design process. Levy and Kimber (2009) have also helped to develop a meta-language to discuss the design, content, and cohesion of multimodal texts. In their work, Levy and Kimber (2009) purposefully sought to see how students and teachers could talk about multimodal texts in ways that would improve learning and the final textual product. This meta-language was used to help scaffold instruction and was utilized to develop a decision-making matrix that helped to support students in making adjustments to their final multimodal texts. This meta-language provided teachers and students with a shared understanding of the key features of multimodal texts and helped to support the student's representational fluency, or ability to communicate meaning across and through multiple modes of communication.

One of the most essential elements in helping students create quality multimodal representations can be accomplished by teaching students about the elements of design. Research in this area has shown that in order for students to become competent designers of multimodal text they must be taught about multimodality and elements of design (Bearne & Wolstencroft, 2006). According to Bearne & Wolstencroft (2006), this means that students must be taught: (a) how various semiotic modes and mediums communicate meaning both independently and together; (b) how to make design choices that best communicate the intended meaning to a given audience; and (c) how to "read" the messages created by various semiotic resources. Tippett (2011), has also identified several categories that are part of this design process. These categories include examining the choice of color and semiotic resources as well as identifying how students plan their representations, how well they understand the conventions and rhetorical purposes of each semiotic resource, or mode, and how students select the information they want to represent. All of this is part of understanding the rhetorical devices and purposes of multimodal texts. Bezemer and Kress (2010), best describe the role of a designer. They have identified the process of design as that of carefully choosing semiotic modes, mediums, sites of displays, and frames in order to meet the rhetorical purposes of the designer.

Teachers must recognize that this design process extends beyond the individual interests or learning style of their students. The affordances of each semiotic resources equips it to communicate various scientific understandings for various purposes. Students must understand these modes and each design element at their disposal in order to understand each mode's unique communicative or rhetorical purpose (Prain & Waldrip, 2006). Teachers must equip students to understand that part of their role is to teach students how to choose the best modes, mediums, sites of displays, and frames to represent a particular scientific concept (Waldrip, Prain, & Carolan 2006; Tytler, Prain, & Peterson, 2007). Students must be able to express why they have chosen each mode or medium and why it is the best choice to communicate their message to a given audience

(Kress, 2004). This is part of understanding the literacies of science. Students must learn to replicate the ways in which real scientists represent meaning by practicing it themselves (Kress, 2004).

Steve Moline's, *I See What You Mean: Children at Work with Visual Information* (1995) provides a starting place for helping teachers to understand various ways of representing scientific concepts visually. The last chapter, in particular, provides a discussion of how to teach students about elements of graphic design including the role of layout, typography, and signposts. Specific teaching practices to help student's become designers of multimodal texts are also provided and include suggestions such as: (a) discussing layout, typography, and signposts in multimodal information texts to help students realize how each is used; (b) providing varied opportunities for note-taking that allow students to make lists, create tables and graphs, etc.; (c) encouraging students to "design" and not just "write" texts; (d) use design elements such as boxes, arrows, and headings to organize and sort ideas; and (e) discuss alternative ways of representing a concept that can communicate a message more clearly. Waldrip, Prain, and Carolan (2006) also found that students themselves felt constructing a multimodal representation was much easier when some direction about how to structure the representation was provided. The finding of Gerstner and Bogner (2009) support this idea, in that their research found that students' multimodal texts were of higher quality when scaffolded by the teacher. Such suggestions may scaffold student development in the designing of multimodal representations, but more explicit research is needed to understand the best practices for how to do each of the above.

As students become better at interpreting and constructing multimodal texts, focus needs to then turn to the ability to evaluate multimodal messages from a critical perspective. Literature in this area has begun, but is as of yet very limited. Thompson (2008) has contributed to this limited body of research by suggesting that teachers will need to address how multimodal texts position students as designers and how this influence the identity of the student and his/her worldview. Felten (2008) also recognizes that being able to interpret a multimodal text does not mean that a person possesses the ability to critically analyze the message of the text itself and its construction. Barnford (2003) also alludes to the fact that this evaluation process is key to a student's ability to become fully literate in the use of multiple literacies. Barnford (2003) stated that to be visually literate, a person needed to not only be able to interpret images, but they needed to also be able to understand the role that the cultural context plays in shaping the message created by that image. This evaluation process, is the start of a critical analysis of representations created using multiple semiotic resources. Perhaps, further development in this area will lead to a special development within critical literacy that provides tools and methodologies for a critical analysis of multimodal texts.

Together, these skills of interpreting, constructing, and evaluating multimodal textual representations help students develop not only their literacies of science, but their representational competency and fluency. Representational competency, according to diSessa (2004), is a student's ability to construct, explain, evaluate, and critique the quality of various multimodal representations, whereas, representational fluency is their ability to translate (represent and re-represent) meaning across various modes and representations in order to build conceptual knowledge (see also Waldrip, Prain, & Carolan, 2006). Bezemer and Kress (2010), however, point out, that true translations across semiotic resources are impossible because of the affordances and limitations inherent in each mode. Both representational competency and fluency are indicative of a larger communicative competence (Hymes, 1972). This competency requires students to understand not only the grammatical knowledge of each semiotic mode, but to also understand how that resource is used for rhetorical purposes to communicate meaning in a social setting. As students develop these competencies they become more scientifically literate (Knain, 2006). One of the main goals in developing the various competencies is to help students to represent information in such a way that it models the way scientists participating in the Discourse of science would represent the same information during their laboratory research (Kozma, 2003).

One of the best ways to develop a student's communicative competency and ability to participate in scientific Discourse is to provide multiple instructional opportunities to interpret, construct, and evaluate multimodal representations. Although much work is still needed to discover the extent of the effects of providing students with "representation-rich" pedagogy and learning opportunities, many researchers tend to hypothesize that such experiences will be beneficial in helping students to understand scientific concepts and processes (Waldrip, Prain, & Carolan, 2010). Students need to be given the opportunity to think and process scientific information using multiple representational modes and to extend and enhance current representations through multimodal translation work (Tytler, Prain, & Peterson, 2007). Thompson (2008), believes that such multimodal work requires teachers to evaluate how students are positioned in terms of their identity. This requires teachers to carefully consider how multimodal texts are shaping students' identity and worldview.

Meaning-Making during Scientific Inquiry

The second part of this review focuses on literature available that shows what is currently known about how students are engaged in meaning-making practices during scientific inquiry. This section focuses primarily on how conceptual understandings and misconceptions are identified during inquiry and how meaning-making is connected to the development of scientific literacy.

Demonstrates conceptual understandings/misconceptions. During scientific inquiry, just as much can be learned from what a student knows as can be learned from their misconceptions. Both aspects, show the development of a student's thinking and understanding and how they are engaged in the process of making-meaning. In their 2006 investigation, Tytler, Peterson, and Prain, conducted a study to discover the types of obstacles students faced when trying to represent what happens to particles during the process of evaporation. Using qualitative methodologies such as conducting interviews to hear how students explained their visual representations of this process, they discovered that even representations that were inaccurate could show advancement in a student's understanding and could demonstrate the connections students were making between their conceptual understanding and the representation itself. In this case, both the meaning being made, and the misconceptions present within the representation were informative in regards to the meaning students were making during the inquiry process. One of the major implications of this research study was the idea that scientific concepts and their representations are closely linked. Instructional practices and pedagogy need to focus on how to use these representations to support the conceptual development of students. In doing so, students will develop not only their scientific literacy, but the literacies of science that can model and represent that literacy.

Other researchers such as Kozma (2003) and Sandoval, Bell, Coleman, Enyedy, and Suthers (2000) have also demonstrated the interconnection between the conceptual development of students and their use of multimodal representations as a thinking tool. Kozma (2003), in particular has exhibited that professional scientists possess much more advanced skills at using representations fluently in ways that can communicate and represent scientific understanding across various modes. Representations are used in this fluent manner to reason and negotiate understanding during the inquiry process. Representational fluency is more and more becoming an indicator of a person's literacy skills.

Builds scientific literacy. One of the main goals of scientific inquiry is to build scientific literacy. This next section, will briefly look at how scientific literacy is currently defined, demonstrated, and developed through one's participation in the Discourses of science.

Many definitions of scientific literacy currently exist, but this review focuses its scope to identifying the similarities in how scientific literacy has been defined by national and state agencies determining the objectives for science education in the public schools. These objectives are fundamental in determining for what counts as "science" is today's classrooms. They help to establish the boundaries within which teachers are able and allowed to work.

On the national level, the current understanding or definition of scientific literacy has been strongly influenced by the work of the National Research Council (NRC) (2012) and their development of a *Framework for K-12 Science Education: Practices, Cross Cutting Concepts, and Core Ideas.* This framework served as the basis for the development of the recently released national standards for science education in grades K-12, known as the *Next Generation Science Standards* (NGSS Lead States, 2013) and as such, has been influential in adding to the current definition of scientific literacy. These standards are utilized by states who have adopted the *Common Core.* The title of the NRC framework (2012) itself, provides great insight into how scientific literacy is currently being defined in both the framework and in the subsequent standards outlined in the *NGSS* (2013). The current definition of scientific literacy espoused by leaders on the national level includes an idea that students must not only understand scientific concepts, but that they must also be proficient in the practices of science and understand the concepts that cut across the scope of scientific inquiry (see both National Research Council, 2012; NGSS Lead States, 2013). Both the framework (2012) and the standards (2013) recognize that scientific literacy is developed over a lifetime and involves a progression of learning. The goal of this learning process is to equip students to be able to describe, explain, and make predictions about the natural world so that they can make informed decisions based on a strong foundation of scientific knowledge. According to the framework and standards currently recognized and implemented on the national level, students who are scientifically literate should be able to compose and evaluate the validity of scientific arguments and draw valid conclusions from evidence (National Research Council, 2012; NGSS Lead States, 2013).

Although Texas has not adopted the *Common Core* or the *Next Generation Science Standards (NGSS),* its state standards, known as the Texas Essential Knowledge and Skills, or TEKS (19 Tex. Admin. Code § 112.15 (b) (1-4), 2010) also include objectives for science learning that support a similar definition of what it means to be scientifically literate. According to the state standards, students are expected to not only understand specific scientific concepts as outlined by the standards, but to also demonstrate their ability to engage in scientific inquiry and utilize scientific reasoning (such as critical thinking, scientific problem solving, and the ability to make informed choices).

As indicated above by both the national policies towards science education and the current development of science standards in the state of Texas, scientific literacy is evolving to include more than just a student's ability to understand scientific concepts. The national and state levels governing and guiding scientific education for all K-12 students, espouse that scientific literacy is also about being able to think and act like a scientist through the use of literacies of science.

Scientific literacy is demonstrated in a multiple of ways. The ability to demonstrate these literacies includes being able to use the skills and processes of the Discourse of science by participating in scientific inquiry, using the literacies of science to communicate scientific understanding, and recording the inquiry process in a scientific logbook.

In order to demonstrate their scientific literacy skills, students must be able to utilize the skills and processes of science during scientific inquiry. According to the NRC (2012), some of the skills students are expected to demonstrate include being able to: (a) ask testable questions, (b) use/create scientific models, (c) engage in scientific inquiry, (d) interpret and analyze data, (e) use appropriate mathematical skills to carry out necessary calculations, (f) draw conclusions and communicate explanations, and (g) develop scientific arguments supported with data.

Similar skills are identified by the state of Texas (19 Tex. Admin. Code § 112.15 (b) (1-4), 2010). According to the state standards for fourth grade students, students are expected to be able to: (a) engage in scientific inquiry, (b) use safe practices and appropriate safety equipment, (c) ask "well-defined questions," (c) use scientific tools to make observations and measurements using the metric system, (d) record data, (e) create, represent, and analyze data and the natural world using models, graphs, tables, and charts, (f) draw conclusions from data, (g) use data to support conclusions and evaluate claims, (h) use repeated trials to increase the reliability of their data, (i) communicate findings and scientific concepts in both written and oral forms, and (j) evaluate scientific arguments, explanations, and product claims using data, scientific reasoning, and testing. Many of the skills and processes listed above are learned and developed through the process of scientific inquiry. Scientific inquiry provides students with the opportunity to develop the literacy skills necessary to participate in scientific Discourse.

As students engage in scientific inquiry, they learn to master many of the skills and literacies of science in order to learn and communicate their scientific understanding. It is a set of skills that often develop through on-going participation in the inquiry process--they are skills students learn by doing. Bennett (2011) found that often multimodal representations of science concepts play a significant role in helping students develop their scientific literacy abilities. Waldrip, Prain, and Carolan (2006) also emphasized the direct link between the scientific concept being represented and the representation itself. Whether representations are accurate depictions or not, many representations have been found to advance a student's conceptual understanding (Tytler, Peterson, & Prain, 2006). The important part is that students are given opportunities to practice using, creating, and translating across representations using the various literacies of science so that they can be apprenticed into better ways of representing and communicating scientific knowledge (Waldrip, Prain, & Carolan 2006). As such, they learn not only how to use the skills of science during inquiry, but how to make appropriate design choices to best represent the scientific concept(s) they have been studying or learning about (Kress, 2004). This is a process that is developed by experience and exposure to multiple ways of making-meaning, including learning how to translate meaning across various representations in order to think and reason during the inquiry process (Kozma, 2003; Knain, 2006).

As students are engaged during scientific inquiry, the research indicates that student scientists, just like their more experienced counterparts, record their work in some type of a scientific logbook (Kozma, 2003). Butler and Nesbit (2008) have found that scientific logbooks provide students with a platform for thinking, recording their inquiry experiences, and making sense of their work. It allows students to capture what they have done, describe their procedures, and think about their overall process. Logbooks, or scientific notebooks, can also be used as a means of activating background knowledge (Clidas, 2010). They are used as a place to record the entire scientific inquiry process from start to finish.

The demands of the discipline of science are huge and are best learned by doing. Students learn and develop their scientific literacy by being apprenticed into the scientific community and by thinking, acting, speaking, and behaving like a scientist.

Every community, including the scientific community, has its own ways of making-meaning (Lemke, 1990). This includes embodying various ways of talking, acting, and participating that distinguish it from another community. These ways of being and participating in a community would be what James Gee refers to as Discourse with a "capital D" (Gee, 1990). Discourse with a "capital D" includes the way that members of a community act, think, feel, view, work, talk, and communicate within a certain community (Gee, 1990). As students participate in scientific inquiry they become scientifically literate by using the literacies of science. They are, in essence, being apprenticed into the scientific community and are learning how to use the semiotic practices of that community of practice (Lemke, 1990). This process is essential in the development of scientific literacy. Kozma (2003) found this to be especially true as he worked with both expert and novice chemistry scientists. Chemistry students new to the community of practice were able to work in collaboration with and mimic the representational patterns used by more experienced scientist, thus demonstrating this apprenticeship in practice. This has significant pedagogical implications for how science instruction is taught to students.

Multimodal Representations and Meaning-Making during Scientific Inquiry

This final section of this literature review focuses specifically on what is known about how multimodal representations are being used for meaning-making during scientific inquiry in order to identify a hole in the literature for future research. This section looks specifically at the role of multimodal representations in inquiry and how representational competency/fluency develops over time.

Role of multimodal representations in inquiry. Multimodal representations used during inquiry serve two primary purposes: they provide documentation of the inquiry process and they provide a product of the scientific understanding gained during the inquiry process.

Sandoval et al. (2000), conducted a study to discover how multimodal representations are able to support the meaning-making processes, or epistemological learning, of students in science. In their research, support is provided for the idea that multimodal representations can be used to scaffold the efforts of students to communicate, negotiate, and evaluate scientific meanings. The work of Tytler, Peterson, and Prain (2006), also supports these general findings. Their 2006 study evaluates the representational challenges students faced when trying to describe the process of evaporation. Their findings, as previously stated, indicate that representations created by students, even representations that are inaccurate, have the ability to show a student's understanding and the type of connections they are making. Their research indicates, that representations and scientific conceptual understanding are directly linked. Instructional practices and pedagogy need to focus on how to use these representations to support the conceptual development of students. This type of instruction has the potential to build not only the student's scientific literacy, but the literacies of science necessary to demonstrate that literacy.

Other researchers such as, Kozma (2003) and Sandoval et al. (2000) have also demonstrated the interconnection between the conceptual development of students and their use of multimodal representations as a thinking tool during the inquiry process. Kozma (2003), in particular has exhibited that professional scientists possess much more advanced skills at using representations fluently in ways that can communicate and represent scientific understanding across various modes. Representations are used in this fluent manner to reason and negotiate understanding during the inquiry process. Representational fluency is more and more becoming an indicator of a person's literacy skills.

The development of representational competency and fluency over time. The National Research Council's, *Framework for K-12 Science Education: Practices, Cross Cutting Concepts, and Core Ideas* (2012), has demonstrated a current view of scientific literacy as one that develops over a period of time. This development occurs as students are engaged in using the skills and process associated with scientific inquiry and as they are being apprenticed into the ways of thinking and acting like scientists (Lemke, 1990; Gee, 1990). Closely associated with the development of scientific literacy is the development of representational competency and fluency.

As students are engaged in the processes of inquiry, they are directly engaged in the literacies of science used by the larger scientific Discourse and are learning the best ways to represent and communicate scientific understandings (Kress, 2004). Over time, and with practice, students learn to communicate scientific meanings more effectively (developing their representational competency) and become more proficient at translating and negotiating meanings across various modes, thus developing their representational fluency (Prain, Waldrip, & Carolan 2006; Bezemer & Kress 2010). This development is often supported by support from teachers or others who are more advanced in these skills (see Vygotsky, 1978; Lowe, 2000; Amettler & Pinto, 2002; Stylianidou, Ormerod, & Ogborn, 2002; Kozma, 2003; Leewalter, 2003; Chittleborough and Treagust, 2008; Coleman, Bradley, & Donovan, 2012).

Summary

The purpose of this review was to provide a critical analysis of the most essential theoretical and empirical research currently available pertaining to how multimodal representations are used during scientific inquiry to make meaning and build scientific literacy in order to identify a gap in the literature that will lead to future scholarly research in this field. Specifically, it attempted to present an overview of the current theoretical and empirical research available on multimodal representations, meaning-making during scientific inquiry, and how multimodal representations are being used to make meaning during the inquiry process. In doing so, it sought to explain:

1. The salient features of multimodal representations identified in research.
2. How are multimodal representations currently used and understood by teachers and students in the classroom.
3. What the literature say about the role of multimodal representations during scientific inquiry and how this contributes to meaning-making.
4. How multimodal representations support meaning-making during scientific inquiry.

The research above found that salient features of multimodal representations included the mode and medium being used to communicate or represent meaning and the social affordances or limitations that each mode provides (Kress, 2004). The site of display (Kress, 2004; Bearne & Wolstencroft, 2006) and how the social setting frames the message are also essential to describing multimodal representations (Bezemer & Kress, 2010).

Teachers within science education in particular are beginning to realize the importance of drawing students' attention to the specific features of multimodal texts and how each are used to communicate messages to specific audiences. Pointing out features and visual elements used within multimodal texts during guided "reading" of multimodal texts allows students to begin to develop this awareness (Lowe, 2000; Amettler & Pinto, 2002; Stylianidou, Ormerod, & Ogborn, 2002; Leewalter, 2003; Chittleborough and Treagust, 2008; Coleman, Bradley, & Donovan, 2012). Providing this type of support and multiple opportunities for students to interpret, design, and evaluate multimodal representations is essential in helping them to develop representational competency and fluency (diSessa 2004; Prain & Waldrip, 2006; Bezemer & Kress, 2010).

During scientific inquiry, multimodal representations can be used to demonstrate scientific understanding, negotiate meaning, and report findings (Sandoval et. al, 2000; Kozma, 2003). The representations created by students can show what is understood by the student and where the student has misconceptions about a scientific concept (Tytler, Peterson, & Prain, 2006; Waldrip, Prain, & Carolan, 2006). Students also learn how to participate in the Discourse of science by learning the literacies of science expressed through multimodal representations (Bennett, 2011).

Although these many areas have helped shape our current understanding, many areas of multimodal textual representations and how they are used during scientific inquiry need to be explored further.

Implications for Further Research

Many advances in understanding multimodal representations and their ability to communicate/represent meaning within a community of practice have been made, but much more work is needed to create a richer picture of their communicative potential. This review of literature has shown that research is needed in order to further build on our general understanding of how multimodal representations are created and used within particular social practice; to further our understanding of the rhetorical capabilities of the various semiotic resources used during the creation of multimodal representations; to continue to develop methodological approaches that will support research; to develop our understanding of the role technology plays and will play in shaping these texts; to fully understand the ability of the texts to build the conceptual knowledge of students in various disciplines; to build on what is known about the best pedagogical practices to support a student's abilities to understand and design multimodal texts; and to gain a picture of what students already know and understand about multimodal texts and the design process.

Researchers have most often used Social Semiotics to describe the general nature of multimodal representations and how they are used in various social communities of practice to make meaning. This work has provided the basis for understanding the nature of multimodal representations, but more work is needed to further develop a meta-language that will allow researchers, teachers, and students alike to discuss the features of multimodal representations and how to best understand and design such texts.

Research methodologies and tools for multimodal discourse analysis also need further development to successfully analyze the multitude of semiotic resources currently in play and the current practices surrounding their usage. Current analysis focuses on verbal resources and images (Kress 2004; Bezemer & Kress, 2010), but must extend to other semiotic resources as well to be a true methodological tool for analysis.

With constant developments in technology and evolving communicative and representational social practices, there will also be a need for growing understanding of semiotic resources and how they are used in various social communities of practice. This can be accomplished by developing a better understanding of the rhetorical devices inherent in each semiotic resource and how those devices are used to communicate/represent meaning.

This understanding is essential to building the current knowledge base about how multimodal representations are able to be used to scaffold and build disciplinary knowledge. Although some literature is provided on the connection between representations and conceptual developments, further work is needed to support this connection and to see how it is applied to particular communities of practice.

Other research to support improved pedagogy using multimodal representations will need to focus on how to best build representational competency and fluency. If representational competency and fluency are indicative of scientific literacy, research into how to best equip teachers to provide and support this development is necessary. Part of developing this competency is the continued development of a meta-language to describe multimodal textual representations so that researchers, practioners, and students are all able to interpret, critique, and evaluate multimodal messages. This includes preparing disciplinary teachers with the literacy skills necessary to equip students as consumers and designers of multimodal representations (Kress, 2004). Although, some research in the interaction between semiotic resources within a text has been conducted (see Moreno & Mayer, 2000; Mayer, Hegarty, Mayer, & Campbell, 2005; Harskamp, Mayer, Suhre, 2007; Eliam & Poyas, 2008; Bezemer & Jewitt, 2010), further work is also needed to understand the interplay of various modes within a multimodal text and to understand how these interactions are used by designers to create meaning.

Further work is also needed to examine the misconception held by teachers in regards to multimodal representations. Current research has already shown that some teachers have confusion about the appropriate selection of semiotic modes. Teachers often assume that student/teacher interest or learning style should dictate this choice (Prain & Waldrip, 2006). Attention must be given to understanding the extent of a teacher's current knowledge about the features of multimodal texts, how to best teach those features, and how to support the interpretations and creation of texts.

Closely connected with this, is the need to understand what student's already know about the multimodal texts they are creating and the extent of their knowledge about the rhetorical affordances of each mode. Although Kress (2004), indicates that designers must understand the importance of their design choices as they construct multimodal textual representations, very little literature exists describing what students already know about their role as designers and how they use these designs to purposefully make meaning.

Due to this lack in the current literature, this research in particular seeks to add to the current body of literature available by providing information about the nature of multimodal textual representations created by sixteen fourth grade students and how these students create meaning during a scientific inquiry project on plant adaptations. It looks specifically at how the students' themselves describe and choose to represent the meaning they are making through the use of multimodal texts and how this is indicative of their participation in the larger Discourse of science.

CHAPTER III

METHODOLOGY

Introduction

The previous chapter provided a review of the literature that highlighted several areas still needing to be addressed by research in the area of multimodality, especially in light of science education. Kress (2004), recognizes the importance of students learning the rhetorical potential of each semiotic mode so as to make intentional decisions during the design process. Research is yet needed to understand what students know about these rhetorical devices and how they are currently employing them in their multimodal textual science in their multimodal texts to communicate their scientific understanding during the process of scientific inquiry. As such, this study seeks to contribute to the gap in the literature presented in chapter two by using a social semiotic approach to multimodality to describe the nature of multimodal texts created by sixteen fourth grade students during scientific inquiry and the meaning these students are generating as they construct these representations.

To address the specific goals of this study, a qualitative methodology was used to explore the nature of what fourth grade students' multimodal textual representations created during scientific inquiry and how these texts are being used to make meaning.

This chapter discusses the research study's design, the data collection methods and the analysis procedures used to answer the study's research question.

Overview

As a teacher-researcher, a collective case-study with a cross-case analysis of those cases was chosen for this teacher action research project (Stake, 1995). Data was collected from several individual students within the same "bounded system" and then compared to provide insight into how students were making-meaning as they created multimodal representations during an inquiry-based investigation on plants (Stake, 1995).

Teacher Action Research

Teacher Action Research (TAR) was suitable to help guide the collection of the qualitative data necessary for this collective case study and cross-case analysis due to the reflective nature of education itself. In the classroom the job of a teacher is never finished. There are always ways to improve instruction. Teaching, by its nature, is a recursive process similar to Teacher Action Research (TAR) itself and qualitative data is often overlooked as an excellent source of information. As a reflexive practioner, Teacher Action Research (TAR) provides an opportunity for me to purposefully reflect on my role as a practitioner and to study and work directly with the kids that I teach. This is important because I believe that teaching should be constructive and emancipatory in nature and should value the input of the students as much as possible. The qualitative data collected from individual students can be compared and analyzed for patterns across all cases to identify what my students understand about creating multimodal representations and the patterns of meaning-making that my students are currently engaged in so as to make future decisions about how to best guide this process so that conceptual development continues. Because students, as well as teachers, are invested in the outcomes of the learning experience, they should be recognized as valuable partners in the research process. The combination of combining qualitative cross-comparison analysis of case studies while engaging in teacher action research allowed me to focus on problems that were specific to the needs of the school and district where I work and that directly benefited our students was important for the growth of my students and my own personal growth as an educator (Pine, 2006). According to the National Science Education Standards "Another way to learn more about teaching science is to conduct classroom-based research..." (National Research Council, 2012, p. 58).Teacher Action Research (TAR) was and is a powerful tool for just such classroom-based research. I believe that students can be the best teachers of what they know, how they are engaged in making meaning, and how I can better teach them.

Teacher as Researcher

As an educator, I have a total of thirteen years of teaching experience. Eight of these have been with my current school district where this study was conducted. Twelve of those thirteen years, I have had the opportunity to teach science. For the last four years, I have specifically served as the science lab teacher for all of the fourth, fifth, and sixth grade students on our campus. Three years ago I was also asked to serve as the science coordinator for our campus. My role allows me to plan and teach alongside all eight of the science teachers that teach grades four-six in our district.

Students in our district have the opportunity to come to the science lab for two forty minute sessions a week in grades four and five, and one time a week for thirty-five minutes in sixth grade. During the time in the lab, students actively engage in scientific inquiry pertaining to the concept being studied in their science class. During the inquiry process, the student's classroom science teacher and I work together as co-teachers to guide the students through the inquiry process. It is primarily my responsibility to plan for these sessions, but I often do so in conjunction with input and cooperation from the grade-level teachers during our weekly planning meetings. Our goal is to provide the students with as many hands-on experiences as possible to make learning come alive.

As an educator I believe that learning and meaning-making are both social processes. This is in alignment with the work of Lev Vygotsky (1962; 1978). I have come to believe, like Vygotsky, that children learn best when they are involved in social interactions with their peers and with their teachers and are working at an instructional level that corresponds to what Vygotsky refers to as their “Zone of Proximal Development”—that point between what the students can do with help and what they can do independently. In these interactions, teachers or students with more knowledge are able to support and scaffold the understanding of the other learners. These more experienced learners are what Vygotsky referred to as the “more knowledgeable other,” or (MKO) (Vygotsky, 1962; 1978). Because of my strong belief in this view, I do often have my students work in collaborative groups so that they can support one another and help one another with the scientific inquiry process.

In science this social support is absolutely essential and is a part of participating in the Discourse of science itself. Both Lemke (1990) and Gee (1990) reflect this socialization process of learning. According to Lemke (1990) and Gee (1990), students are apprenticed into the Discourses of science. They learn how to talk, think, and participate in special ways of making meaning by engaging in those various practices. Often this apprenticeship practice happens as students are supported in their efforts by others who are more knowledgeable in the discipline itself. In the science lab there are times where I provide this assistance for my students, but more often than not, my students provide this support for one another as they work collaboratively through the inquiry process.

Due to the nature of this research and the chosen methodology, I served both as the principal investigator and as a teacher-researcher during the course of this study. My role included planning and guiding the fourth grade students through the inquiry process as they participated in an investigation about the structures and functions of plants. As the teacher-researcher, I was responsible for planning, preparing, and providing all of the necessary resources and instruction for the inquiry process. During this process, I kept field notes and digitally recorded reflections about the student's inquiry process and the multimodal products that they generated.

Collective Case Study

This research study attempted to describe the nature of multimodal textual representations and meaning-making created by fourth grade students during scientific inquiry and to find a pattern across these multiple cases. Case study has been defined by Creswell (1998) as an investigation of a system that is "bounded" by time and location. Specifically, this collective case study focused on the work of sixteen 4th grade students (or sixteen multiple cases) of one school district in rural Texas during a two week period of instruction. It attempted to provide a detailed description of multiple cases participating in scientific inquiry in order to make a comparison and draw conclusions about the larger context or setting (Stake, 1995).

My decision to include multiple cases originated as an idea to compare the nature of multimodal representations across various ability levels as indicated by the school district where this data was being collected. During the process of data collection, I realized that each student brought to light valuable pieces of data that could help answer the research question guiding this study. In lieu of this realization, and as the result of a discussion with my academic advisor, it was decided that all students who volunteered to be participants in this study would be included in the data set.

Qualitative data for this case study was collected from the student's multimodal textual representations, the digital recordings of the students' descriptions of their multimodal representations, transcripts of those descriptions, field notes, and lesson artifacts. The data collected was then analyzed across the sixteen cases to provide a rich description of the themes and patterns that emerged in regards to what students know about multimodal textual representations they were creating and how they were using their representations to make meaning in this particular context.

Cross-Case Analysis

As part of the collective case study, a cross case analysis was provided to describe the themes and patterns found across the various cases (Stake, 1995). This analysis was guided by an analytical framework based on the literature reviewed in chapter two of this paper. This framework provided a theoretical lens for describing the nature of the multimodal representations created by the fourth grade students and how these constructions were connected to the meaning they made during scientific inquiry. Specifically, the analytical framework focused on three major areas: the Discourse of science represented in the multimodal text, the meaning students are making, and features of the multimodal representations used by the students. A discussion of how this framework was developed follows in a subsequent section. Each case was analyzed with this framework individually, and then summaries from the sixteen individual cases were compared using this framework and data display charts to draw conclusions and in order to provide a rich description of the themes and patterns emerging from this study.

Case Selection

This section describes the context for this research study, how access was gained to the site, and how the particular cases or participants were selected for this study.

Context

This study was conducted in a small, rural, Title I school district just south of Dallas, Texas. According to the 2012 Snapshot provided by the Texas Education Agency, 80.3 % of our school district qualified as economically disadvantaged, and 22% of our students were designated as having limited English proficiency (LEP). All of the fourth through sixth grade students in the district were and are housed on the intermediate school campus. According to a district presentation by the board of trustees, the enrollment for the school district during the time of this study included 161 fourth grade students, 176 fifth grade students, and 188 sixth grade students.

Students selected to participate in this investigation were fourth grade students who were engaged in scientific inquiry as part of their normal curriculum at the intermediate school where these students' attend school full time. Their regular schedule allowed them to come to the science lab with their classroom science instructor two times a week with each session lasting a total of forty minutes. During their time in the lab, students worked with lab partners (generally groups of 2-4 students) to conduct investigations and record their data.

Scientific communities of practice are and have been created between myself, my co-teachers, and the students that we teach. In the science lab, we work together to engage in the process of scientific inquiry and to express our scientific understanding through multiple forms of representation and communication. As we do, we embrace our role as scientists and support each other in our meaning-making practices. The science lab is a place full of hands-on investigation, small and large group conversation. It is a place where we communicate ideas in mathematical and graphical ways and/or in written form. The form/mode of communication is chosen by the purpose or function of the message we are communicating (Halliday, 1978).

The fourth grade students who participated in this investigation have had the opportunity to develop their scientific skills by participating in scientific investigations all year long. They have become experienced at the practices of science and the use of scientific tools to collect and record their data. They were familiar with using logbooks and have become increasingly comfortable with the use of scientific language. They were able to communicate using many of the common literacies of science with little or no support from the teacher and understand the purpose of each. These factors were strong indicators that the intermediate students at our school were and are learning how to participate in the Discourse of science by active engagement in "doing science." This has not always been the case at our school and we continue to work hard to develop these skills in both us as teachers and in our students.

Access

As the science lab teacher, I saw each fourth and fifth grade class two times a week and each sixth grade class one time a week as part of their normal curriculum. Each class period lasted approximately 35-40 minutes. The fourth grade students were specifically chosen to participate in this investigation because of convenience of their regularly scheduled lab times and the ease at which access could be gained for this study.

The scope and sequence set forth by the school district where I am employed and where this research was conducted and the proposed timeline for this investigation also made the fourth grade an appropriate grade-level for this research study.

Participants and Case Selection

The participants for this collective case study and teacher action research project included both myself, as the teacher-researcher, and sixteen students who have volunteered to participate in this study.

As the science lab instructor for the school district selected for this study, I taught all eight of the fourth grade classes in the school district. During their normally scheduled lab time, the study was described to all of the fourth grade students in detail and all questions the students had about participating in the study were answered. Students who were interested in volunteering to participate in the research study were given an informational letter and a consent form to take home to their parents. Signed consent forms were returned to me directly. The consent forms were numbered in the order that they were returned. Initially, because the classes were leveled by the school district, I was going to choose the first two students from each level (low, medium, and high) to be my representative samples for this investigation. Because each student brought their own unique perspective to the inquiry process and creation of multimodal texts, I decided to expand my data set to include all data samples. As such, each of the sixteen students became one of the cases used in the cross-case analysis.

Although all of the fourth grade students participated in the same scientific inquiry process, only the data from the sixteen students who volunteered for this study by returning signed consent forms were considered for this cross-case analysis. These students were asked to participate in their lab activities as normal. Multimodal textual representations created by these students during the inquiry process were collected for data analysis. Digital recordings made as part of the normal lab investigation were used to document each students' multimodal text creation process and to record their reflections about the process they used to generate their text. The texts created by the students and the digitally recorded reflections also provided data about why the students choose to create their representations the way they did, the meaning it held to them, and how it was connected to the inquiry process they were engaged in. All data for this study was collected during the normally scheduled lab times so that no additional time requirements were necessary.

Overview of the "Bounded System"

The overview of the "bounded system" provides information about the overall context of the lesson that each of the sixteen students or cases were involved in by describing the state mandated objectives guiding the lesson, by discussing the normal curriculum for the students in the science lab, by providing the general timeline for this study, by explaining the overall lesson format, and by describing my expectations for the students as the teacher-researcher.

Lesson Objectives and Normal Curriculum

Each lab class had the opportunity to learn about a plant investigation that they would be involved in as part of their final science unit on plant and animal adaptations. This unit is part of the district's larger required curriculum for all fourth grade students that encompasses instruction both in the science lab and in the fourth grade science classrooms. The state objectives addressed in this unit are explained in detail and are available on the Texas Education Agency's website (http://ritter.tea.state.tx.us/rules/tac/chapter112/ch112a.html). A copy of the objectives taught in this unit are listed below:

> (4) In Grade 4, investigations are used to learn about the natural world. Students should understand that certain types of questions can be answered by investigations and that methods, models, and conclusions built from these investigations change as new observations are made. Models of objects and events are tools for understanding the natural world and can show how systems work. They have limitations and based on new discoveries are constantly being modified to more closely reflect the natural world.
>
> (1) Scientific investigation and reasoning. The student conducts classroom and outdoor investigations, following home and school safety procedures and environmentally appropriate and ethical practices. The student is expected to:
>
> > (A) demonstrate safe practices and the use of safety equipment as described in the Texas Safety Standards during classroom and outdoor investigations; and
> >
> > (B) make informed choices in the use and conservation of natural resources and reusing and recycling of materials such as paper, aluminum, glass, cans, and plastic.

(2) Scientific investigation and reasoning. The student uses scientific inquiry methods during laboratory and outdoor investigations. The student is expected to:

(A) plan and implement descriptive investigations, including asking well-defined questions, making inferences, and selecting and using appropriate equipment or technology to answer his/her questions;

(B) collect and record data by observing and measuring, using the metric system, and using descriptive words and numerals such as labeled drawings, writing, and concept maps;

(C) construct simple tables, charts, bar graphs, and maps using tools and current technology to organize, examine, and evaluate data;

(D) analyze data and interpret patterns to construct reasonable explanations from data that can be observed and measured;

(E) perform repeated investigations to increase the reliability of results; and

(F) communicate valid, oral, and written results supported by data.

(3) Scientific investigation and reasoning. The student uses critical thinking and scientific problem solving to make informed decisions. The student is expected to:

(A) in all fields of science, analyze, evaluate, and critique scientific explanations by using empirical evidence, logical reasoning, and experimental and observational testing, including examining all sides of scientific evidence of those scientific explanations, so as to encourage critical thinking by the student;

(C) represent the natural world using models such as rivers, stream tables, or fossils and identify their limitations, including accuracy and size;

(4) Scientific investigation and reasoning. The student knows how to use a variety of tools, materials, equipment, and models to conduct science inquiry. The student is expected to:

(A) collect, record, and analyze information using tools, including calculators, microscopes, cameras, computers, hand lenses, metric rulers, Celsius thermometers, mirrors, spring scales, pan balances, triple beam balances, graduated cylinders, beakers, hot plates, meter sticks, compasses, magnets, collecting nets, and notebooks; timing devices, including clocks and stopwatches; and materials to support observation of habitats of organisms such as terrariums and aquariums; and

(B) use safety equipment as appropriate, including safety goggles and gloves.

(10) Organisms and environments. The student knows that organisms undergo similar life processes and have structures that help them survive within their environment. The student is expected to:

(A) explore how adaptations enable organisms to survive in their environment such as comparing birds' beaks and leaves on plants (19 Tex. Admin. Code § 112.15 (b) (1-4, 10), 2010).

This overall unit required the fourth grade students to participate in both classroom and laboratory investigations as part of their normal curriculum. In the classroom, these activities included learning about plant life cycles, the structures and functions of plants that help them survive in various climates, and how seeds travel. Students also had the opportunity to engage in scientific inquiry and experimental design during their normally scheduled science lab time.   During their time in the science lab, the fourth grade students were able to engage in scientific inquiry as they examined the structures and functions of plants that help them survive in various environments. Although these two settings both provided instruction for the fourth grade students and were both essential in helping the students to learn the required objectives outlined in this unit, the scope of this study was limited to the laboratory setting only and to understanding the multimodal textual creations generated as part of the science lab time. As part of the normal curriculum assessment for this unit, students were also given the opportunity to digitally record and share their multimodal representations to discuss how/why they created the texts the way they did, and to talk about the connection between their multimodal texts and the scientific inquiry process they were using during the plant investigation.

Timeline

In order to collect data to answer the research question for this study, five, forty minute inquiry sessions for this study were conducted on May 20th, May 22nd, May 29th, June 3rd, and June 4th. A timeline and general outline of the laboratory activities for those days are listed in Table 1.

Table 1

Outline of Laboratory Activities

Day 1 40 minutes	Day 2 40 minutes	Day 3 40 minutes	Day 4 40 minutes	Day 5 40 minutes
Introduced scientific inquiry project choices for plant investigation unit. Collected student-generated multimodal representations and digital responses Collected lesson plan resources, description and digital responses of my teaching	Collected student-generated multimodal representations and digital responses Collected lesson plan resources, description and digital responses of my teaching	Collected student-generated multimodal representations and digital responses Collected lesson plan resources, description and digital responses of my teaching	Collected student-generated multimodal representations and digital responses Collected lesson plan resources, description and digital responses of my teaching	Culminating project for plant investigation unit. Collected student-generated multimodal representations and digital responses Collected lesson plan resources, description and digital responses of my teaching

Each forty minute class followed a format similar to the following:

Sample Schedule

3-8 minutes	Introduction/communication of expectations/goals for the day's inquiry session
27-32 minutes	Independent/group work time/teacher-researcher circulated to guide, support, and help students to move forward in their design process/Digital responses--students took turns sharing/recording their responses after they had finished their textual creations or when they were eager to share an important aspect of their design or creation process.
5 minutes	Summarized/reflected/shared and cleaned-up

The total time commitment of the five sessions included in the scope of this study required a maximum of 150 minutes for each participant. The individual time commitment, however, varied due to individual response times of each student while recording their digital responses. Each response was approximately 2-3 minutes in length over five consecutive class periods. Total time for digitally recorded responses per child was approximately 10-15 minutes. Creation of multimodal texts per child ranged from 10-30 minutes each. Over the five class periods the total time requirement for each student was 50-150 minutes.

All of the assignments described above are part of the students' normal curriculum and did not distract from the students instructional time, nor did they require anything of the student that they would not normally be asked to do as part of the scientific inquiry process of their regularly scheduled lab times.

Lesson Structure

During the scheduled inquiry investigation, students worked in groups of three or four as they participated in an investigation about the structures of plants and seeds and how those structures help the plant survive in various climates. While doing so they created multimodal representations to document their learning and inquiry processes.

Students began this investigation by setting up a logbook. They were provided with a simple piece of 11x18 construction paper that had been folded in half. Inside the construction paper were several sheets of blank white paper. Instructions to set up a cover, title page, and table of contents were provided, but students made the decisions of how to design these pages themselves. Once the students logbooks were set up, they were then to work with their lab partners to record what they already knew about plants and seeds and then to begin their investigation. Their instruction sheet directed them to start with making leaf observations. Students were to decide for themselves the type of data or observations they were going to make, the order they were going to make these observations in, and the tools necessary for these observations. They were also asked to consider how to organize their information in their logbooks. Students were required to examine at least three different types of leaves and to observe or collect data on at least five different characteristics of each leaf. Student questions were answered when asked, but the students were encouraged to dialogue and think through this task with their lab partners first and to come up with a plan. Once each group was able to demonstrate that they had a plan, they were allowed to begin investigating and working at their own pace.

As the students worked, both I and the classroom science teacher circulated the classroom to observe the students. Reminders of the requirements were given as necessary, but the students were left to work uninterrupted for most of the lab time.

In order to pace the students' efforts, some limits on time were established such as, "today will be your last day to complete your observations. Please try to get as much done as possible." This was done in order to help the kids pace their investigation so that they had the opportunity to observe both leaves and seeds

Expectations of the Inquiry Lesson

As the students participated in this inquiry investigation, my desire was to see them use the skills and tools that we have taught them to guide their own inquiry investigation about plants. I wanted them to use the resources available and to make wise selections about the tools available that would give them the most information about the leaf or seed they were examining. I also was keenly interested in seeing how they choose to represent their data/observations in their logbooks. Both what they could and could not do, how they choose to spend their time, and what they valued most during this investigation gave me insight into their developing scientific literacy and overall ability to participate in scientific Discourse.

One of my main goals, however, was to see specifically what meaning the students were generating during this process. As a science teacher in the state of Texas, we face a huge challenge of equipping our students for the 5th grade science STAAR test. The preparation for us begins with the fourth grade students. We are desperately trying to provide the fourth grade students with a foundation they needed to be successful on their 5th grade test and we try to do so in as authentic way as possible, keeping the focus on "good science" and not just "test prep." The reality is, as a science teacher, I want my students to not only be able to think and act like scientist, but to also have the conceptual knowledge they need to truly understand the discipline of science as well. The students' multimodal representations and the explanations they provided during this investigation helped me to see what and how my students were thinking. I was also indirectly able to gain insight into areas of my teaching that were weak and needed to be addressed.

My expectations as to the actual multimodal representations themselves started out very limited. I was honestly not sure what I would see from my students at all. I hoped that they would assimilate some of the components of instruction like how to set up a data table into their own recording and was thrilled when they did. I also was very pleased to see the many variations on the data tables. I also had hoped to see that the students would represent the small details of these representations like titles and headings that we try to stress the importance of on a regular basis. Most of all, I was just curious to see what the students could do without being given direct instruction. I wanted to see their authentic constructions created during meaningful practice of inquiry. I wanted to know what they thought was important.

Data Collection

During this research investigation, data were collected from the sixteen fourth grade volunteers participating in this study. Each of these students represented a singular case.

According to Creswell (1998), case study provides an in-depth description of a case based on multiple sources of data. These data sources may include: interviews, field observations, documents, archival data sources, or artifacts collected from the site. For this investigative study, and in order to best answer my research question, the data collected during this investigation occurred in two phases.

Phase 1: Observations and Fieldnotes

The first phase of data collection focused on making observations and recording field notes as students engaged in the inquiry process. During this time, students were given an instruction sheet describing what was required during their two-week investigation on plant adaptations. Students were to work with their lab partners to develop a plan for their investigation on leaves and seeds, being sure to incorporate the minimal requirements set forth on the instruction sheet. Primarily, this required students to create a plan that would allow them to study three different leaves and seeds at their table. A minimum of five characteristics were supposed to be studied for each one. The students were to work together to decide how to record and document their work in their logbooks.

As the students worked, I walked around making sure that students were working and answered questions only when solicited to ensure that students were making decisions on their own as much as possible. The student's science teacher who remained in the lab with me during these sessions, as she normally does, was also instructed to answer questions only when solicited and to allow students to make decisions about how to best represent their learning. During the inquiry process I kept a daily log and field notes in order to document my observations and reflections. Digital recordings were also made to capture my own personal reflections of this process with my kids. I also made sure that I took pictures of lab set-up and the information provided about resources available to the students that were posted on the chalkboard. Samples of student instructions and reference materials were also collected as artifacts.

Phase 2: Digitally Recorded Reflections

Phase two of my data collection process involved digitally recording my students as they described their multimodal representations of the inquiry process. The process of digitally-recording my student's reflections is a normal part of their curriculum and both students who were participating in the research study and those who were not spent time describing their logbooks to me. During these recording sessions, students were very generally asked to tell me about their logbooks. I specifically wanted them to guide me through their multimodal representations so that I could see what was important to them. Occasionally, I would solicit more information from my students very informally by asking leading or clarifying questions about something they had just shown me or I would ask them to go into more detail if they seemed to be rushing past a page quickly. My main goal, was to interfere as little as possible.

During this phase of data collection my own personal digitally-recorded reflections, direct observations, daily log, and field notes continued. My co-teacher continued to monitor and answer questions as necessary to support students in the inquiry process and to ensure that all students were working. A summary of the data collected during both phases of this investigation is found in Table 2.

Table 2

Summary of Data Collected across the Sixteen Cases of Student Data

Data Source	Number of Entries
Student Logbooks	16
PDF Version of Student Logbooks with Memos	16
Digitally Recorded Reflections	20
Transcripts of Digitally Recorded Reflections	15
Field Notes	5
Daily Logs	5
Personal Reflections	3
Other Additional Artifacts	
• Lab Instruction Sheet	17
• Structure of Leaves Booklet	1
• Leaf Characteristics Book	1
• Seeds Book	1
• Seed Dispersal Cards	1
• Photograph of Table Set Up	1
• Photograph of Chalkboard	1

Data Analysis

The data analysis for this research study was guided by the qualitative analysis process outlined by Miles & Huberman (1994). As such, the patterns that emerged from the data were a result of a recursive process involving data reduction, the creation of data display charts, and drawing conclusions. The data analysis process involved three main steps: data reduction, data display, and drawing conclusions (Miles & Huberman, 1994). Miles and Huberman (1994), describe the data reduction process as a means of simplifying and changing the data by making selections, summarizing the data, or by looking for larger patterns. The coding, or data reduction, process helps inform how the data will be displayed on a matrix or chart. A data display is used to systematically and visually represent the data. Once displayed, initial conclusions can be drawn and tested. This section provides an overview of how I used this recursive process to analyze the data collected for this study.

Data Reduction

The first step in the analysis process was to organize all of my data by digitizing the multimodal texts created by the students. All student logbooks holding the multimodal textual representations created during scientific inquiry were scanned and digitally saved as PDF files. Copies of these files were then printed. Digital-recordings of the students describing their multimodal texts were previewed and notes from the student's recorded reflections and from my initial observations of the students' texts were recorded as memos on the PDF copies of the logbooks in order to engage in an initial process of open coding.

Units of analysis were delineated by the natural breaks provided by the designer of the multimodal texts. This unit could encompass one section on a page, a page at a time or multiple pages depending upon the text. The sample found in Figure 2 shows two separate units of analysis on a singular page. The first unit of analysis contains the student's plan for their seed investigation and the bottom half of the page contains the data collected during the seed investigation. An example of a unit of analysis found on a singular page can be found in Figure 3. The student is showing what he/she already knows about plants before he or she begins the investigation. The student used a t-chart to organize his/her current understanding. In each example, the analysis focused on the meaning and on the way that meaning was being represented.

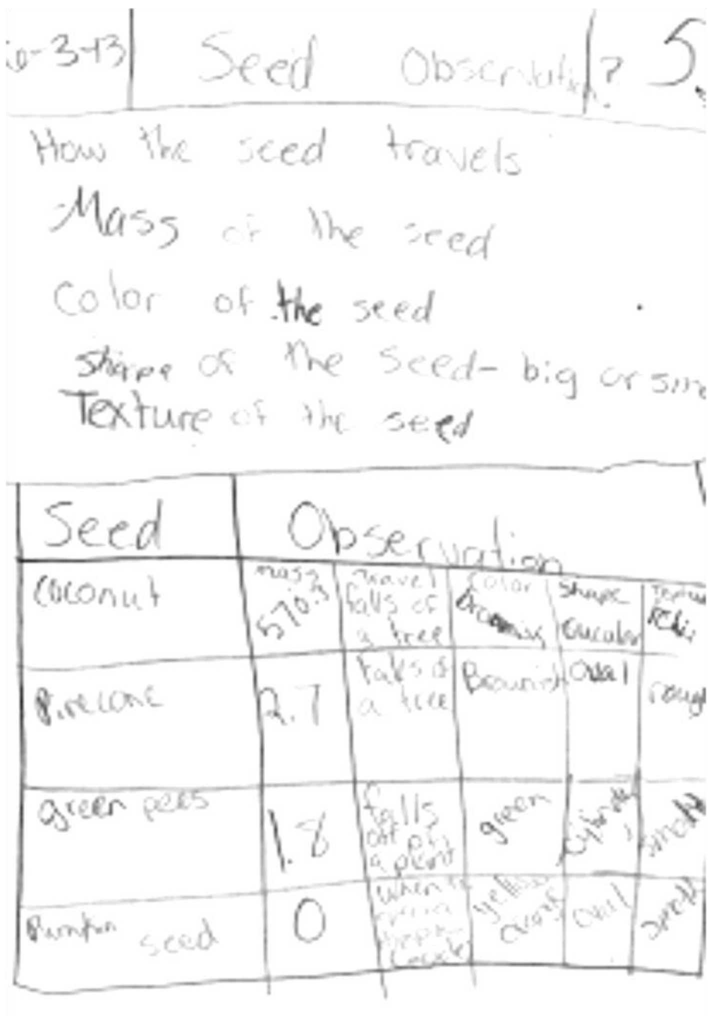


Figure 2: Two units of analysis on a singular page

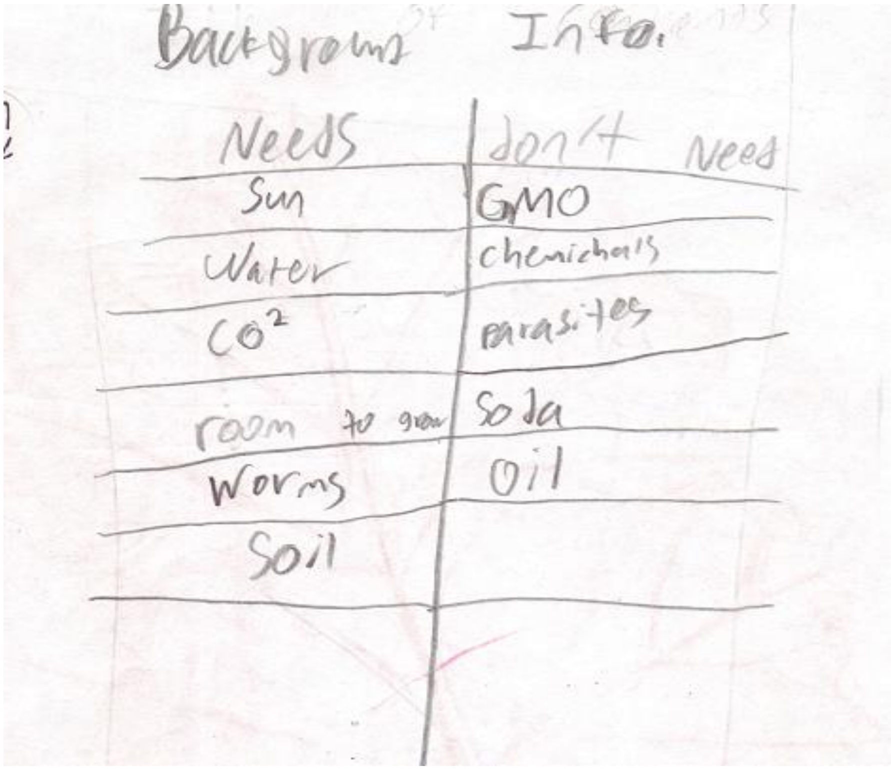


Figure 3: One unit of analysis on a singular page

The third example provided in Figure 4 is an example of meaning that is spread over two pages. In this example, the student is making observations of an oak leaf, but part of the data is found on page two of his/her logbook and the data table containing information about the oak leaf's mass is found on page four. These were looked at together and separately. Together they showed what the student was attending to in regards to the oak leaf itself. The data table itself was also looked at individually to show what the student knew about how to represent the data as a scientist.

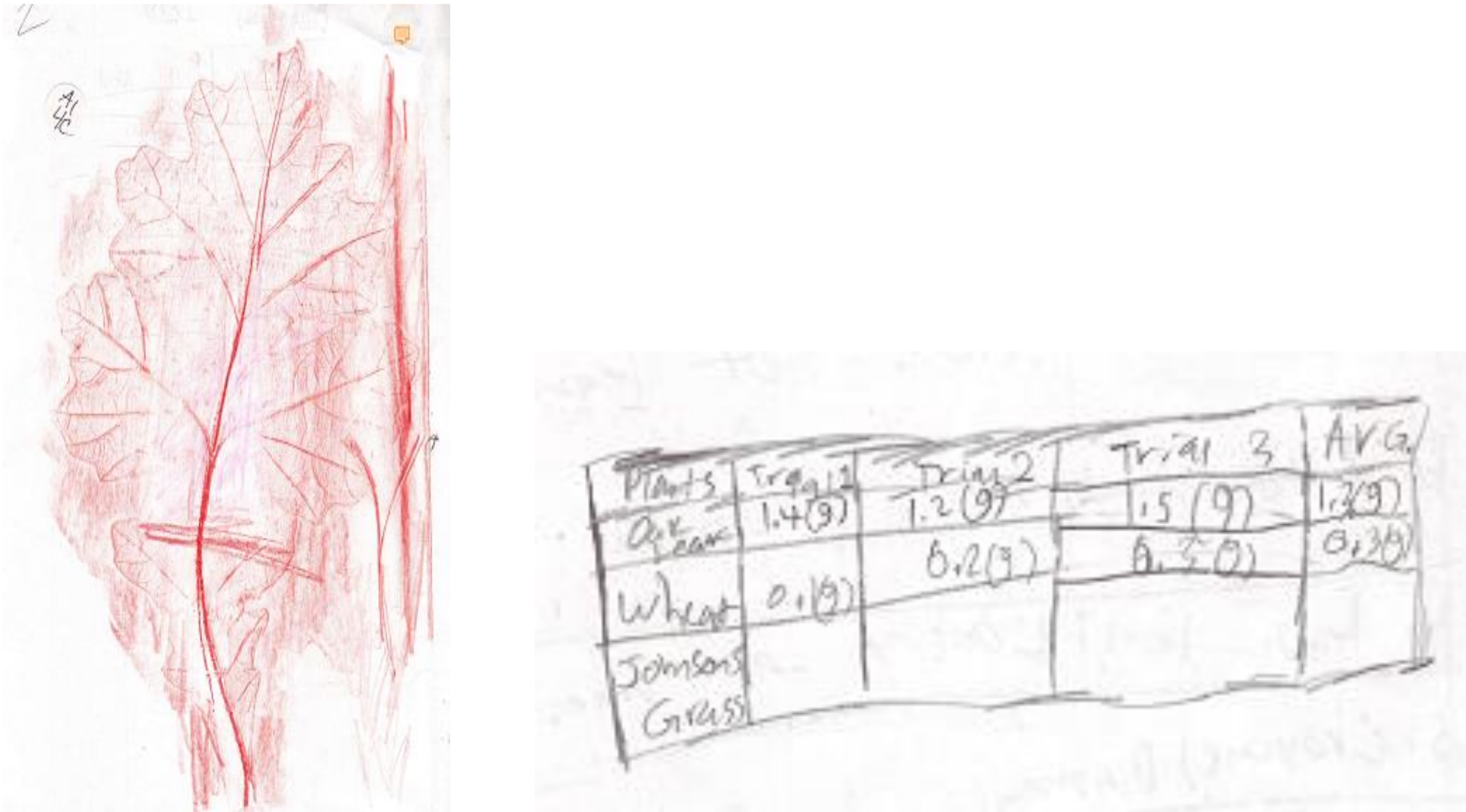


Figure 4: One unit of analysis spread over multiple pages

Once the data was stored digitally and memos were recorded, I began the process of transcribing the digital-recordings for each data sample. Additional memos based on my observations of the transcripts were added to PDF copies of the logbooks.

During this open ended approach, some of my initial observations included: (a) that the students were attending to the scientific value of accuracy in representing their data; (b) that the way the students were choosing to represent their data was influenced by prior instruction; (c) that they were using multiple forms of representations including charts, lists, diagrams, etc.; and (d) that their measurements used a combination of metric and customary units.

At this point, I consulted with my advisor. Information from this open-ended approach proved to be overwhelming and had to be narrowed. In order to continue the data reduction process, it was decided that I needed to examine how the current research on multimodal representations had previously looked at multimodal texts and to use this to build a conceptual or theoretical framework that would allow me to focus particularly on data that would allow me to answer my research question. This process will be described more fully in the next section. As a result of the meeting with my advisor and of my review of the literature, I created a matrix of multimodal features including aspects that would help me to understand the purpose of the text being created, the intended audience, the meaning that was being represented, and the composition itself. In total, this original matrix included sixteen features spread across these four larger categories. It was much too large to deal with the data adequately. My advisor recommended that I collapse the sixteen features into three or four manageable categories. The resulting data display chart condensed the sixteen features into five major headings for consideration: (a) participation in scientific discourse; (b) creating meaning; (c) creating textual representations; (d) teacher, and (e) other. I then tested the display chart by using it to code or display the data from one of my cases before attempting to utilize it for all of my sixteen cases.

After using the display chart to represent data from one of my cases, my advisor and I met one more time to discuss the effectiveness of my theoretical framework and the data display chart I had created. It was decided that I should continue to use the same chart to analyze the remaining cases.

After completing the analysis and display chart for four or five of my cases, I came to realize that the last two headings on the data display chart were unnecessary. Information about teacher influence was included as a data source itself for each of the categories, and the other column was being underutilized in the data reduction process and therefore was not needed. I consulted with my advisor one more time about this redundancy, and a decision was made to remove these additional headings. I used the revised display chart to represent my data for all sixteen of my cases.

Literature shaping the theoretical framework for analysis. In order to develop a framework to analyze the process and products of meaning making as represented by multimodal representations and to understand what students know about how to create multimodal representations, I needed to start with a strong understanding of the assumptions behind the use of multimodal representations in science. Social Semiotics provided this starting point. The work of Kress and Jewitt (2010) provided some foundational pieces from which I could begin this development process.

A summary of their assumptions is as follows:

- Meaning is communicated through the use of various modes and semiotic resources. These modes and resources help a person design how they will represent or communicate their message.
- Messages and modes of representation/communication are shaped culturally, socially, and historically.
- Communicative events are the sites where meaning is made. They happen when meaning is produced by using the semiotic resources and modes available.
- Multiple representations of one meaning are often possible, but designers must understand that certain messages are better or more easily represented in one mode rather than another. Each mode has its own affordances and limitations.

In the elementary science classroom, students are inducted into the Discourses of science and the use of scientific literacies through the process of scientific inquiry. In this reciprocal relationship it is the inquiry process that scaffolds and develops the students' understanding of the practices and literacies that are necessary for engagement in the Scientific Discourse itself. Students of science must become acquainted with the various modes of communication used by the scientific community and the form and function of each mode so that they may develop their ability to critique and construct their own scientific representations. It is through continued practice constructing and deconstructing scientific meaning using these various semiotic modes of communication that students are able to make the best design decisions to help them communicate or represent their meanings in the best possible way.

Prain and Tytler (2012) have been key in extending this view of Social Semiotics in a practical way to student representations during scientific inquiry. Prain and Tylter (2012) used three lenses to interpret how the creation of representations created by students during an investigation on evaporation supported scientific learning. These three perspectives included the semiotic perspective, the epistemic perspective, and the epistemological perspective. In this study the focus of the semiotic perspective sought to provide information about the way students made meaning in science through the use of symbolic and material tools. The epistemic perspective provided information about how the construction of representations supported the development of conceptual knowledge during scientific inquiry, and the epistemological perspective allowed the researchers to glean understanding on what the students can know by participating in the development of representations using the semiotic tools available to them. The categorization that I selected for my analysis framework started with these three broad categories, but I wanted to be able to look at more than the construction of meaning in multimodal texts. I specifically wanted to also consider the role the larger Discourse of science played in shaping the multimodal representations constructed by students, the semiotic resources and modes the students were choosing to use in their constructions of meaning, the understanding they had about how to use these semiotic resources as rhetorical devices, and the role I played and my expectations surrounding the textual constructions of my students. I needed categorizations that were a bit broader in scope so that I could look at the multiple factors influencing the meaning my students were making during their inquiry process.

Another influential work that influenced the final construction of my analytical framework came from Harrison (2003). In her work, Harrison alluded to the idea that many of us are aware of the rhetorical devices used in print, but are often less familiar with similar devices used by other modes such as image. Harrison shared an analytical tool that can be used to "see" and understand how these rhetorical devices are used to create meaning through the use of still images. This was highly influential in the fact that I wanted to "see" exactly what meaning my students were creating not solely in the verbally dominated mode of written expression, but also how the images and other semiotic resources they choose supported their overall ability to communicate and/or represent their message. Harrison, as well as others, have based their work on the theoretical field of Social Semiotics because it is a field that allows us to continue to make these type of extensions from an understanding of meaning being constrained to written language alone to a broader, multimodal understanding of meaning-making.

The Development of the Multimodal Analytic Framework

In order to understand the nature of the multimodal representations being created by students during scientific inquiry and the meaning they were making during this process, I started by conducting a review of the current literature discussing how multimodal texts support learning and elements of understanding their deconstruction and construction. My view of these works initially was guided theoretically by the theories of Social Semiotics (Kress & Jewitt, 2010). The works of Prain and Tytler (2012) and Harrison (2003) were also based on these theoretical underpinnings and provided a basis for the creation of a very detailed matrix from which I began to create an analytical framework. As discussed in the previous section, my preliminary matrix was compressed as part of the data reduction process and in consultation with my advisor to focus specifically on five main categories during my analysis: (a) participation in scientific Discourse, (b) creating meaning, (c) creating textual representations, and (d) teacher expectations. An additional column for other observations was also added to create my own analytical framework. After a subsequent meeting with my academic advisor and as the analysis process progressed, I realized that the Teacher Expectation column and the Other column were unnecessary. The data from those sections were being represented elsewhere. As a result, data reduction compressed the analytical framework into the categories depicted in Table 3.

Table 3

Multimodal Analysis Framework

Participation in Scientific Discourse	**Creating Meaning**	**Creating Textual Representations**
Participation in Scientific Discourse is defined by: • **Language and Practices of Science** (Gee, 1990; 1999). • **Participation in Learning Communities as an Extension of the Scientific Community** (Stepanek, 2000). • **Communicating Scientific Understanding with Multimodal Representations** (Kozma & Russell, 1997).	Creating Meaning takes into consideration the following: • **Scientific Literacy Skills** (National Research Council, 2012) • **Representation Competency and Fluency** (diSessa 2004; Prain & Waldrip, 2006; Bezemer & Kress, 2010) • **The Meaning-Making Process and Product** (Schwartz & Bransford, 1998).	Creating Textual Representations includes: • **Semiotic Resources/Modes** (Kress, 2004). • **Cultural, Social, Historically Shaped Affordances** (Kress, 2004). • **Representational Competence and Fluency** (diSessa 2004; Prain & Waldrip, 2006; Bezemer & Kress, 2010)

My final analytical framework encompassed three major categories that would be used to complete a more focused coding or reduction of the data. These categories included: (a) participation in scientific Discourse; (b) creating meaning; and (c) creating textual representations.

Participation in scientific Discourse. Participation in scientific Discourse was the first major category of the analytical framework. It focused on how the students used multimodal representations to participate in the larger Discourse of science (Gee, 1990). This area in particular looked at how the students used languages and practices of science, how they participated in the learning community of the science classroom, and how they communicated their scientific understanding with multimodal representations.

A major part of learning science is learning how to speak and talk like a scientist, or learning the literacies of science (Lemke, 1990). Students must learn how to see the world the way other scientists do by doing and participating in the languages and practices of science. During the inquiry process, students learn to use scientific tools and objects to gather data and to represent their findings using the same means and methods of other scientists. They are acculturated into the practice of learning how to be and act like others in the scientific community. They begin to view the world in a similar way and develop their abilities to communicate and represent meaning within that social context in appropriate and meaningful ways. Learning science is more than just learning science content, it is learning to be scientifically literate.

A science classroom is the perfect place for these student scientists to learn how to engage in the languages and practices of science. In the science lab, students become part of a learning community that is representative of the larger scientific community and Discourse. It is a place that is supportive of their developing practice as a student scientists. As they practice ways of making meaning during the inquiry process they are able to develop their skills of speaking and thinking like a scientist (Stepanek, 2000).

A final part of identifying a student's participation in the Discourse of science is developing their ability to represent and communicate meaning. During scientific inquiry students often create multimodal representations using the literacies of science accepted by the larger scientific community of practice to represent and re-represent their scientific understandings (Kozma & Russell, 1997). Their competence and fluency representing these concepts is a skill that develops over time as they become more and more adept at the literacies of science.

Creating meaning. The second part of the analytical framework looked specifically at how meaning was being made during the scientific inquiry process as it may be indicated within the multimodal representations of the students. It took into consideration the scientific literacy skills of the students, the students' representational fluency and competency, and meaning-making as a process and a product of inquiry.

One aspect of making meaning is developing the literacy skills necessary for that to happen. As discussed previously, scientific literacy is much more than just knowing scientific content. According to the National Research Council (2012) it includes being able to: (a) ask testable questions, (b) use/create scientific models, (c) engage in scientific inquiry, (d) interpret and analyze data, (e) use appropriate mathematical skills to carry out necessary calculations, (f) draw conclusions and communicate explanations, and (g) develop scientific arguments supported with data. As students engage in these literacy skills they are also actively engaged in making meaning.

Another aspect that creating meaning takes into account is the ability of the students to represent scientific understanding competently and fluently. Many meanings in science can only be communicated by using a combination of multiple modes. One mode alone is often not enough to meet the communicative demands of the discipline of science (Guo, n.d.). As such, students must learn to represent meaning utilizing multiple modes. The ability to construct, explain, evaluate, and critique multimodal representations is what is known as representational competency. Students develop this competency through active participation in scientific inquiry as part of the scientific Discourse of their classroom learning community. Representational fluency is the ability of students to represent meanings across various modes or their ability to connect various representations in significant ways (Prain & Waldrip, 2006; Bezemer & Kress 2010).

A final component of creating meaning, is the understanding that meaning-making is both a process and a product. Both the designing process and the multimodal representation product itself are key in helping a student to acquire their conceptual understanding in science (Schwartz & Bransford, 1998).

Creating textual representations. The final section of the analytical framework for the focused coding process included looking specifically at the textual representations being constructed by the students. It focused on identifying the semiotic resources/modes being used; the recognition that all modes have social, historical, and cultural affordances;

and looking at what the choice of modes and representations themselves indicated about the overall representational competency and fluency of the students.

All multimodal representations are constructed by various modes or semiotic resources. Any resource that can be used to create meaning is considered a semiotic resource (Halliday, 1978; Lemke, 1990). Theses modes or resources may include the use of: language, gestures, drawings/graphics, mathematical expressions, dance, etc. Semiotic resources can be used individually or in conjunction with other resources/modes to make meaning. In order to make meaning within a multimodal text, students must gain the ability to design texts that best communicate/represent their messages using the most appropriate modes and semiotic resources available to them (Kress, 2004).

A second consideration within this category, was the recognition that each of the semiotic modes/resources is bounded by cultural, social, and historical affordances (or potentials) and limitations that influence the message that can be communicated/represented by the students (Kress, 2004; Bearne & Wolstencroft, 2006). As designers, students must realize what resources are available to them and how to best use these resources to communicate/represent their message within the boundaries provided by each particular mode.

Looking at the textual representations created by the students also provided insight into the representational competency and fluency of the students. Both representational competency and fluency are processes that develop over time. Looking at the multimodal representations of the students can give insight into what the students knew about how to best design or represent meaning and what areas were still developing. The more they were able to competency and fluently represent scientific understanding the stronger their grasp on the literacies of science.

Multimodal Data Display Chart

In order to continue the process of reducing my data, I created a chart based on the multimodal analytical framework described in the previous section. The purpose of this chart was to serve as a lens to help me attend to various aspects of the children's work and to specifically address my research question about the nature of multimodal representations created by the students and the meaning the students were making from their representations. The chart placed the three categories for analysis as headings across the top: participation in scientific Discourse, creating meaning, and creating textual representations. The first column had a section for each of the data sources that was used during the data reduction process. These data sources included: the child's own words about his/her multimodal representation, examples found in the child's text, affordances and teacher expectations. A final row was added to the chart to complete analytical summaries during the next stage of the analysis process. An example of the multimodal data display chart used to complete a focused coding of each student's data is shown in Table 4.

Table 4

Multimodal Data Display Chart

	Participation in Scientific Discourse	Creating Meaning	Creating Textual Representations
Child			
Text			
Affordances/ Teacher Expectations			
Analytic Summary			

Individual case analysis. For each child, I began the analysis process by reading their transcript and listening to what they said about the way they created their text and what this meant to them. I also listened to the digital recordings specifically to hear what influenced them to make their design decisions. Were they coming to decisions by working with their lab partners? Were they relying on what we had done in the lab previously? These observations were recorded in the child section of the multimodal data display chart under the appropriate headings.

The second part of my analysis focused on the students' textual representation itself. I focused primarily on the elements represented by the text. I wanted to know what the felt was important to incorporate into his/her representation and how he/she did so. As I reviewed the textual representations, I made observations about how the students were participating in scientific Discourse, how they were creating meaning, and how they constructed their texts. These observations were recorded in the text portion of the multimodal data display chart.

The final section of teacher affordances was the section that allowed me to provide a bit of insight into the classroom dynamics, previous instruction provided to the students, comments about my own expectations of what it meant to participate in the scientific Discourse of our classroom. Although this section is more subjective, it was an essential piece in understanding the context in which the students were creating meaning and it did clarify the affordances available to the students during their design process. Previous experience has either given or not given them the tools and resources to know how to make meaning in some circumstances. Other advantages and limitations came from the tools and resources physically at their disposal and the number of opportunities they have previously had to encounter these resources. These were some of the key factors considered in this section. Observations made for this section were also recorded on the multimodal data display chart.

Table 5 provides an example of the data reduction and data display process using the multimodal data display chart for one of the cases.

Table 5

Multimodal Data Display Chart Example (Child One)

	Participation in Scientific Discourse	Creating Meaning	Creating Textual Representations
Child	Leaf rubbing showed exact image Organization based on leaf characteristics Recorded measurements on data table while using tools. Weight-grams-TBB Calculator--averaged trials—approximation	Background Information categorized into needs vs. not-needs Exact image of leaf--leaf rubbings Found weight, repeated trials, averaged to show approximation.	T-chart used to categorize background information Numbered steps used for procedure Data table used to record measurements
Text	Plan included the tools to be used and how each was going to be used during investigations. Focused primarily on mass. Used repeated trials. Plan, procedure, data order differed.	Listed needs and not-needs in background information. Leaf rubbing shows size, leaf margin, veins Generated designations for each leaf and seed observed. Used words to respond to reflection questions.	Information organized using t-charts, lists, data tables, and written responses. Leaf rubbing-red

Affordances/ Teacher Expectations	Choice of tools and procedure designed by students--plan, procedure, data should be consistent. Must choose three samples and five characteristics for each investigation. List of available tools provided for students. Understood tools--use of each. All measurements/ observations should be accurate/detailed/metric units--recorded in logbook. Selected to use: TBB, calculators, leaf rubbings. Recorded information using t-charts and data table as modeled in class. Repeated trials and found averages as modeled in class.	Choice of tools and procedure designed by students. List of available tools provided for students. Understood tools--use of each. Focused primarily on repeated trials and averages for mass. Other data limited. Repeated trials/averages emphasized in lab. Recorded information using t-charts and data table as modeled in class Used "weight" instead of mass.	TOC organized using district format T-chart and data table followed models provided through previous instruction.
Analytic Summary			

Drawing Conclusions: Analytical Summaries

Once the data for each case was reduced and organized using the multimodal data display charts, an analytical summary of the information in each column was completed for all sixteen of the individual cases. An example of the analytical summaries for one of the cases is provided in Table 6. In the first column of this particular example shows that the student was participating in the Discourse of science in multiple ways. One indication of this participation was noted by the student's use of multiple scientific tools to make both qualitative and quantitative observations of the leaves and seeds. The student had created a research plan and had created data tables and a t-chart to organize his/her information. Although, the research plan and the procedure the child followed differed in order, he/she has shown an understanding that scientists often repeat their measurements, or conduct multiple trials, during an investigation. These skills were indicative of the student's participation in the Discourse of science. In the second column, it was noted that the meaning being created by the student was closely connected to the student's participation in the Discourse of science. The use of the t-chart allowed the student to make a comparison between the "needs vs. not-needs" of plants to show what he/she already knew about plants before beginning the inquiry process. Similarly, the data table allowed the student to organize the measurements he/she was making and to find an average or what the student referred to as an "approximation" of the weight, or mass, of the leaves being observed. The student utilized most of his/her inquiry time to conduct accurate observations of his/her leaves and seeds. A leaf rubbing conducted by this student was also used to help the student identify the size of the leaf being observed, to identify the leaf margin (or pattern of the leaf's edge), and to observe the leaf's veins. The final column summarized the design choices made by the student by identifying what is known about how the student actually created his/her textual representation. In this particular case, the textual construction choices both seemed to be based on experience. The format used for the student's table of contents page followed the guidelines established by our school district for interactive note-booking, even though no instruction was given in this regard. It appears that the student utilized what was familiar to him/her. The same is true with the format of the t-chart and data table. These two organizational patterns are ones that have been directly taught during previous inquiry investigations and are utilized often in the science lab. Although, no direct instruction was provided on how to organize the data for this investigation, the student used formats that were appropriate for the meaning he/she was making and that he/she was familiar with to represent that meaning.

Table 6

Multimodal Data Display Chart with Analytical Summaries (Child One)

	Participation in Scientific Discourse	Creating Meaning	Creating Textual Representations
Child	Leaf rubbing showed exact image Organization based on leaf characteristics Recorded measurements on data table while using tools. Weight-grams-TBB Calculator--averaged trials—approximation	Background Information categorized into needs vs. not-needs Exact image of leaf--leaf rubbings Found weight, repeated trials, averaged to show approximation.	T-chart used to categorize background information Numbered steps used for procedure Data table used to record measurements
Text	Plan included the tools to be used and how each was going to be used during investigations. Focused primarily on mass. Used repeated trials. Plan, procedure, data order differed.	Listed needs and not-needs in background information. Leaf rubbing shows size, leaf margin, veins Generated designations for each leaf and seed observed. Used words to respond to reflection questions.	Information organized using t-charts, lists, data tables, and written responses. Leaf rubbing-red

Affordances/ Teacher Expectations	Choice of tools and procedure designed by students--plan, procedure, data should be consistent. Must choose three samples and five characteristics for each investigation. List of available tools provided for students. Understood tools--use of each. All measurements/ observations should be accurate/detailed/metric units--recorded in logbook. Selected to use: TBB, calculators, leaf rubbings. Recorded information using t-charts and data table as modeled in class. Repeated trials and found averages as modeled in class.	Choice of tools and procedure designed by students. List of available tools provided for students. Understood tools--use of each. Focused primarily on repeated trials and averages for mass. Other data limited. Repeated trials/averages emphasized in lab. Recorded information using t-charts and data table as modeled in class Used "weight" instead of mass.	TOC organized using district format T-chart and data table followed models provided through previous instruction.

Analytic Summary	Plan included tools to be used/purpose for using each tool--both qualitative and quantitative observations made. Repeated trials--averages made using a calculator. Data recorded on data table. T-charts used to compare (needs vs. not-needs) Plan, procedure, data followed different orders.	Primary focus--Weight (mass) found on TBB -measurements repeated three times (trials)--averaged (approximation) Rubbing--shows image of each leaf (size, margin, veins) Used t-charts to make comparisons and data table to record observations.	TOC followed district format T-chart/data table follow previous instruction Numbered lists used to organize information

Cross-Case Analysis

After completing the analytical summaries for each of the sixteen cases, the analytical summaries were put into a second display chart called a cross case analysis chart (see supplemental files). Conclusions for each of the three columns (participation in scientific Discourse, creating meaning, and creating textual representations) were drawn across cases to provide insights into the patterns that were emerging across the multiple cases. Overall themes were then developed by looking at the reoccurring patterns in each of the three coding areas. These findings are discussed more fully in chapter four.

Trustworthiness

In order to ensure the trustworthiness of the findings from this cross-case analysis as well as to provide an external check on the work down throughout this inquiry process, member checks and a peer review of the conclusions from the analysis were conducted (Ely, Anzul, Friedman, Garner, & Steinmetz, 1991; Erlandson, Harris, Skipper, & Allen, 1993; Glesne & Peshkin, 1992; Lincoln & Guba, 1985, Merriam, 1988).

Member Check

In a case study the participants play an important role (Stake, 1995). As such, their verification of the accuracy of the findings is essential in developing the credibility for this type of study. In order to verify the conclusions drawn from the conclusions of the cross-case analysis provided in this research study, two students were asked to confirm the credibility of the findings. The students were shown their logbooks again in order to refresh their memories about what they had done previously. After this preview, I briefly described the analysis process to them. After this description, I shared my interpretation of what I had observed with each student and asked for their feedback in return. The students were given opportunities to expound on anything that I stated and to ask questions. On both accounts, the students felt that the conclusions drawn from the analysis of their data represented an accurate account of their work.

Peer Review

The research process itself was also verified through the process of a peer review (Ely, Anzul, Friedman, Garner, Steinmetz, 1991; Erlandson, Harris, Skipper & Allen, 1993; Glesne & Peshkin, 1992; Lincoln & Guba, 1985, Merriam, 1988). The peer review was conducted with a fourth grade teacher who was present during the data collection process. As such, the teacher participating in the peer review was familiar with the instructions provided to the students, the students themselves, the lab procedures, and was an active part of the learning community in the science lab. During the "peer debriefing sessions," I briefly shared an overview of the data that had been collected and the analysis procedures that I had utilized. The teacher participating in the peer review asked questions about the methods used to analyze the data, the theoretical framework guiding the analysis, the conclusions and interpretations drawn (Lincoln & Guba, 1985). She was able to follow the logic of the studies design and the interpretations made by reading the examples of evidence provided.

CHAPTER IV

FINDINGS

Overview

The purpose of this teacher action research project and collective case study was to utilize a Social Semiotic perspective of meaning-making to provide a cross-case analysis of sixteen fourth-grade students. This study's goal was to richly describe the nature of the multimodal representations constructed by these students during the process of scientific inquiry and to explain how these students made meaning while they were engaged in a scientific investigation. This research study was guided by the following research question: What is the nature of multimodal textual representations created by fourth grade students during the scientific inquiry process?

Multiple sources of data including: student logbooks, PDF versions of student logbooks with memos, digitally recorded reflections, transcripts of digitally recorded reflections, field notes, daily logs, personal reflections, and artifacts were analyzed to answer this research question. The data for this analysis were coded and displayed using a Multimodal Data Display Chart. Three major coding categories were developed and represented in the Multimodal Data Display Chart based on the initial open coding/data reduction process and the literature reviewed for this research study. The coding categories used for analysis included: the student's participation in scientific Discourse, creating meaning, and creating textual representations. Analytical summaries for each individual case were developed based on the data in each of the coding categories. These analytical summaries were then transferred to a Cross Case Analysis Chart for a cross case analysis and comparison of the data. This process allowed several patterns to emerge from the data within each coding category. Conclusions about the patterns found across the cases in each coding category were summarized and added to the final row of the Cross Case Analysis Chart. These conclusions can be found in the appendix.

The data display charts were then used to draw conclusions. As a result, four main patterns emerged for each coding category. Similarities in these patterns across the various coding categories were then used to develop the themes found in Table 8. This table provides an illustration of the patterns and themes that emerged from the data as a result of the data reduction and drawing conclusions from the data display charts used during the recursive analysis process. Each theme will be discussed in detail in the following sections.

Table 7

Overview of the Categorical Patterns and the Overall Themes Emerging from the Data

	Participation in Scientific Discourse	Creating Meaning	Creating Textual Representations
Pattern One	Support of the Scientific Learning Community	Support of the Scientific Learning Community	Use of Graphic Organizers
Pattern Two	Making Qualitative Observations and Quantitative Measurements	Making Qualitative Observations and Quantitative Measurements	Use of Other Design Choices
Pattern Three	Use of Graphic Organizers	Use of Graphic Organizers	Influence of Previous Instruction and Experience
Pattern Four	Influence of Previous Instruction and Experience	Connecting Inquiry to Reflection Responses	Representational Development Over Time

Overall Themes

1. Support of the Scientific Learning Community
2. Making Qualitative Observations and Quantitative Measurements
3. Use of Graphic Organizers
4. Influence of Previous Instruction and Experience
5. Representational Development Over Time

Theme One: Support of the Scientific Learning Community

One of the major findings in the cross case analysis conducted for this study showed that the students' participation in the Discourse of science, the meaning they created, and the way they represented or communicated that meaning were all supported by the learning community established in the science classroom. According to Martin (2007), a learning community includes "structuring the routines and practices of the class to ensure all are treated with respect and given the opportunity to make a contribution to their community." Learning communities are often characterized by a sense of both a "personal and collective responsibility," a "sense of belonging," and an "emphasis on co-operation, rather than competition" (Martin, 2007). During the course of the year while the fourth grade students have participated in multiple investigations in the science lab, they have had the opportunity to engage in practices that have allowed them to develop this type of supportive learning community. The fourth grade students have had the chance to come to the science lab for two forty-minute inquiry sessions a week. During this time in the lab, these students have worked collaboratively with their lab partners to conduct several investigations. As they have continuously worked closely together, the students have developed ways to effectively communicate as a team and have learned how to resolve issues when they arise with little to no outside help—in a sense they have developed a true learning community. The learning community/(ies) established in the science lab are the direct result of the students learning how to collaborate and share responsibility while they are investigating and learning new things in science.

Evidence of how these lab teams supported one another became apparent in the data collected for this investigation. This first theme illustrates how the scientific learning community established in the science lab supported the students ability to participate in the Discourse of science, create meaning, and represent or communicate that meaning through the creation of their multimodal texts on a conceptual, procedural, and linguistic levels.

The science classroom is the perfect place for students to learn how to become scientists as they engage in the languages and practices of science (Lemke, 1990). In this setting, the students are engaged in thinking, acting, speaking, and doing things like scientists. Through the active participation of "doing science", the students learn how to create and represent meaning in ways commonly utilized by the larger scientific community thereby becoming apprenticed into the Discourse of science (Lemke, 1990; Gee, 1990). The data from the multimodal representations created by the sixteen fourth grade students provides an illustration of this finding. Although each team worked a little bit differently and in their own unique way, they all supported one another conceptually, procedurally, and linguistically.

Conceptual support during this investigation can be seen in several ways. The first way that each team provided conceptual support for one another is found in the students' recordings of their background information. As part of the investigative process, the students were instructed to include a section in their logbooks about what they already knew about plants prior to beginning their investigation. Additional information from their lab partners or other classmates could be added to this page as well. This allowed the students to support each other's scientific understandings from the very beginning. The following examples shown in Figures 5 and 6, show how two of the students designated this type of conceptual support in their logbooks by citing the information given to them by other students. The indicators used by these students to cite the sources of their information included a number and a letter that identifies a particular individual in the science classroom and acknowledges that the students have obtained information from an external source. In this particular case, the students were not only adding to their scientific understanding, but they were showing a realization that as scientists they must recognize others for their contributions by providing a citation of their external sources of information.

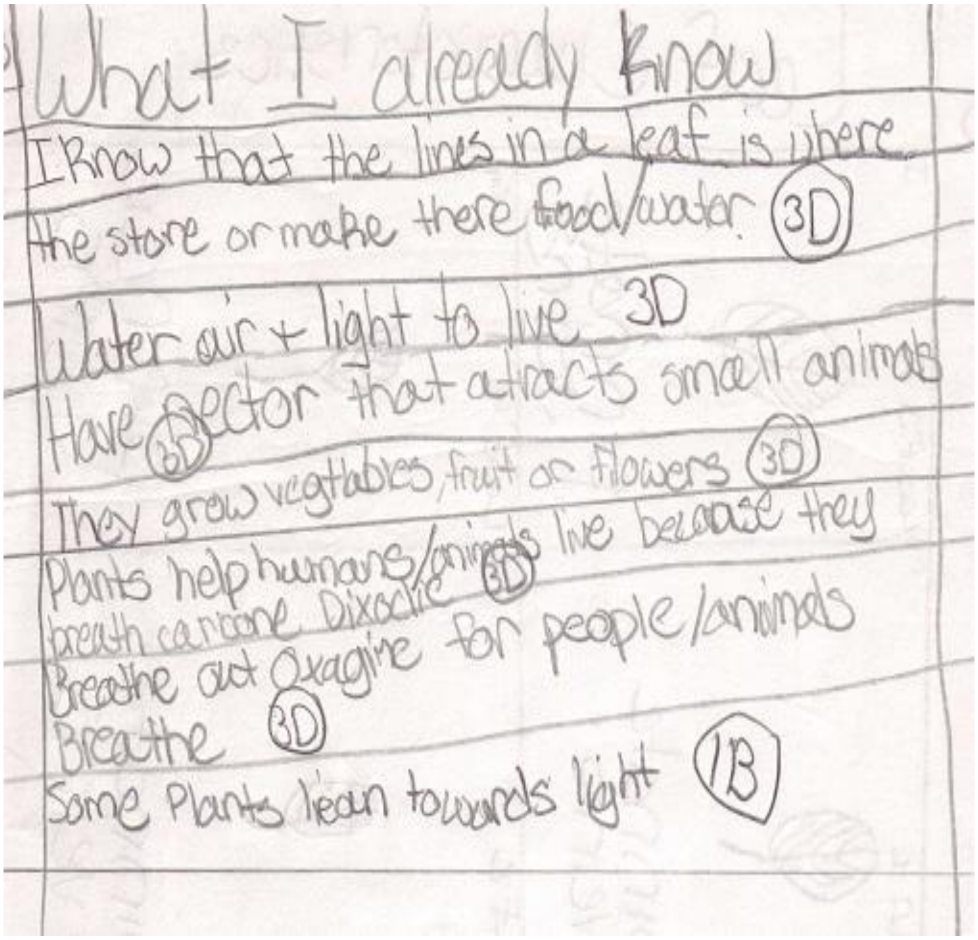

What I already Know
I Know that the lines in a leaf is where
the store or make there food/water 3D
Water air + light to live 3D
Have nector that atracts small animals 3D
They grow vegtables, fruit or flowers 3D
Plants help humans/animals live because they
breath carbone Dixocide 3D
Breathe out Oxagine for people/animals
Breathe 3D
Some Plants lean towards light 1B

Figure 5: Example of conceptual support as indicated by citations for external sources of information

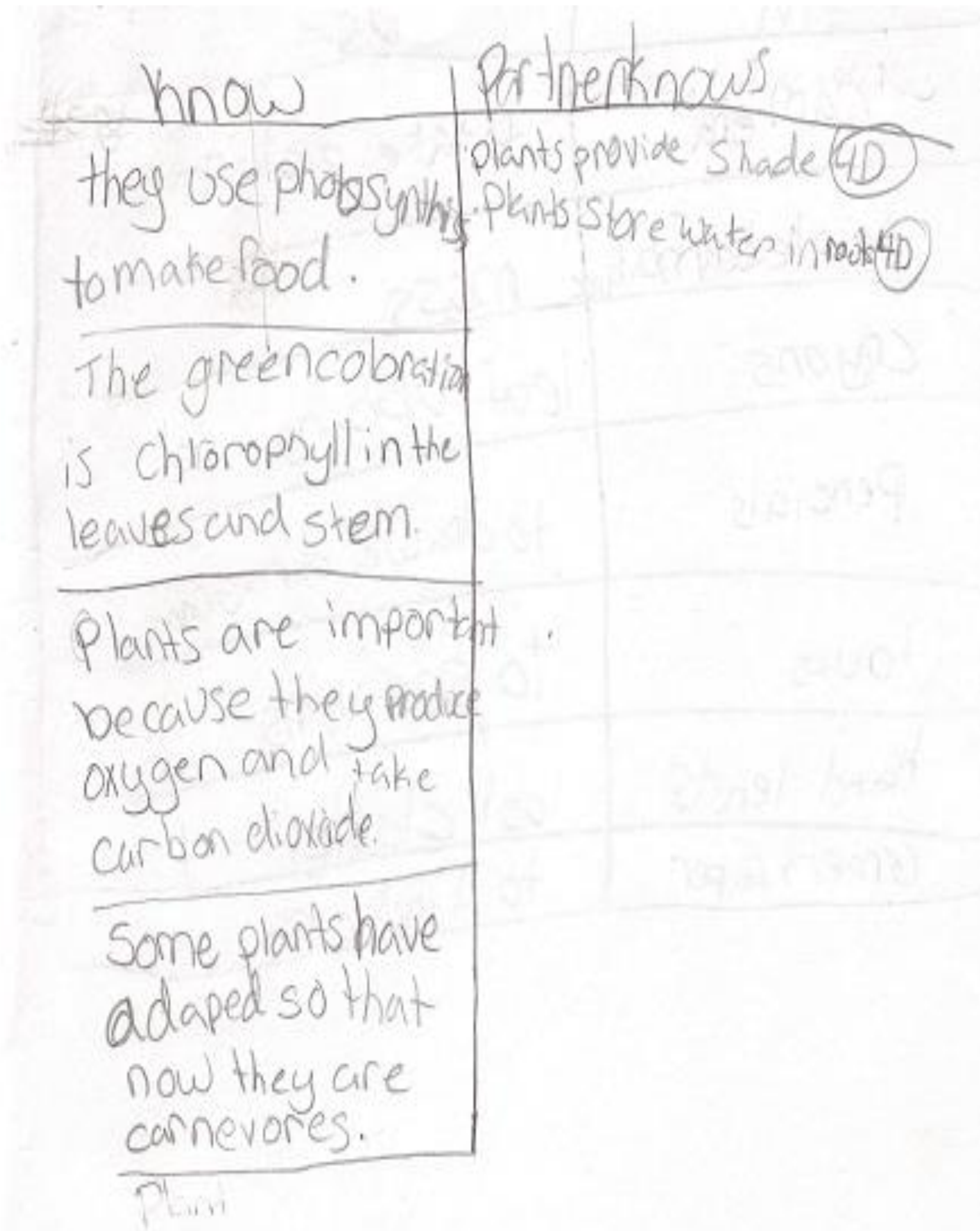


Figure 6: A second example of conceptual support as indicated by citations for external sources of information

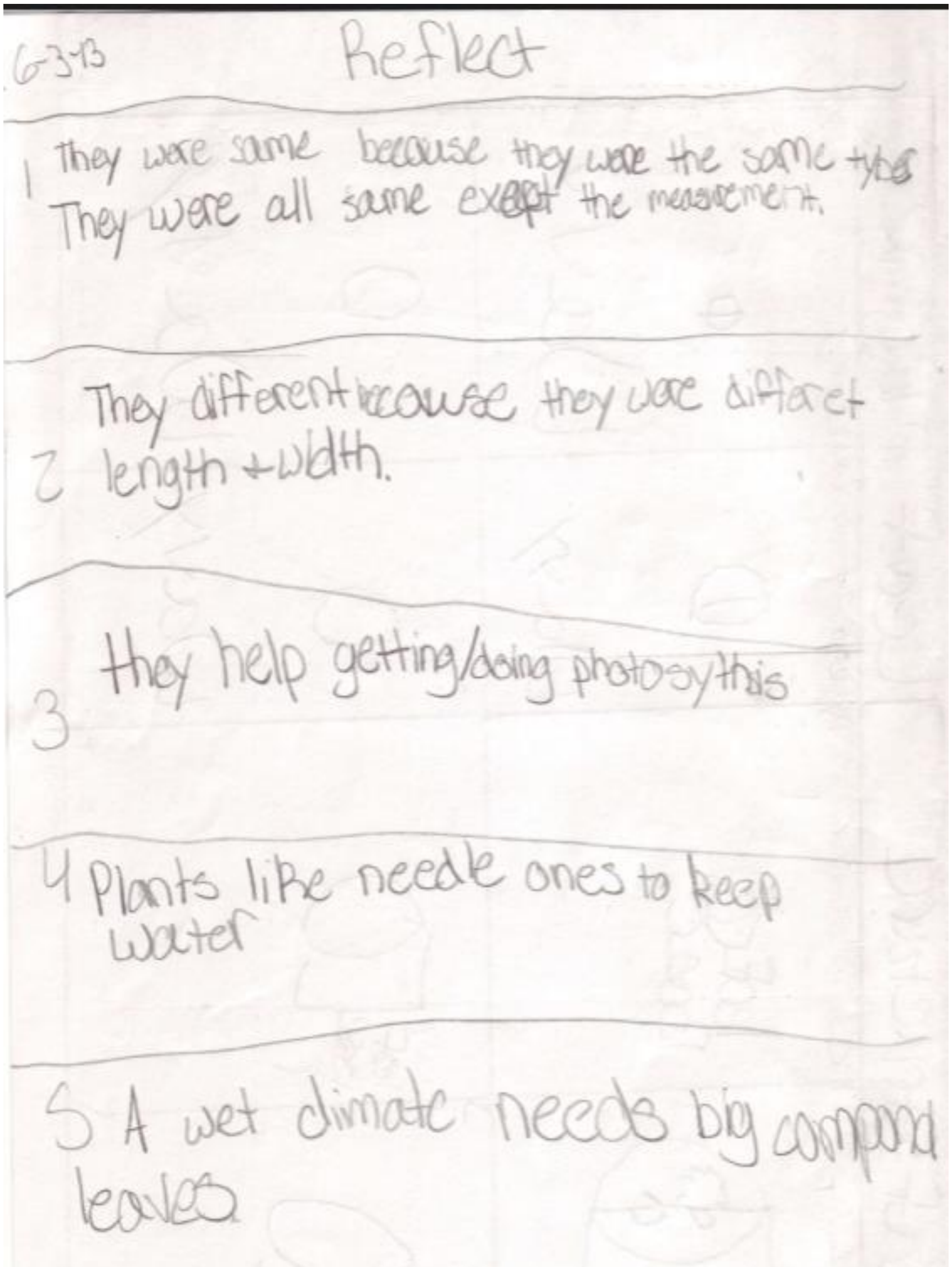
A second example of how the students supported each other conceptually during this investigation is provided by looking at the student responses to reflection questions that followed the first investigation. After completing their investigation on leaves, the students were asked to respond to the following reflection questions:

1. How were all the leaves you observed the same? What did they have in common?
2. How were all of the leaves you observed different?
3. How do you think the leaves of a plant can help it survive?
4. What kind of leaves do you think a plant needs in a dry climate? Why?
5. What kind of leaves do you think a plant needs in a wet climate? Why?

The purpose of these reflection questions was to get the students to make connections between their observations and what they were learning in their regular science class about the adaptations of plants. I wanted them to focus on how the various structures of the leaves helped different plants to survive in their particular environments.

Through direct observation of the students, I noted that each of the lab groups naturally relied on one another to help answer these reflection questions. It was an expected outgrowth of the inquiry process. The students viewed themselves as collaborative teams. The inquiry process in their minds, signified not only the planning and collecting of the data, but continued onward into thinking about what they had learned during their investigative process. This was indicated in the majority of the transcripts by the continued use of the pronoun “we” when explaining this process.

Answering the reflection questions as a team rather than individuals was a natural way for them to continue their collaborative effort. By crafting their responses to the reflection questions as a group, the students were able to support and scaffold one another's conceptual understandings of what they were learning from this investigation. This was later represented in how each student choose to record his/her groups' understandings in their logbook. An example of one group's responses can be found in Figure 7. This particular example is important because it not only provides a record of how this student decided to record his/her groups' understanding of each of the reflection questions, but it also shows how this group used academic language from the reference materials provided to help support their conceptual development. In response to "What kind of leaves do you think a plant needs in a wet climate?" Child 12 states that, "A wet climate needs big, compound leaves." Although this response indicates some misconceptions about this concept, it does show an attempt by this group to not only provide a response, but to do so using the scientific language provided to them in the reference materials. They are utilizing the resources at their disposal and relying on one another to make meaning during the inquiry process.


6-3-13 Reflect

1 They were same because they were the same types They were all same exept the measurement.

They different because they were differet
2 length + width.

they help getting/doing photosythsis
3

4 Plants like needle ones to keep water

5 A wet climate needs big compond leaves

Figure 7: Reflection questions (child 12)

The learning communities established in the science lab were also found to have provided one another with procedural support. As the students worked together many of them collaboratively developed a research plan, created a way to organize their information, and conducted their investigation together. These processes required the groups to make several procedural decisions as a team. This decision making process can be seen both in the transcripts provided and the textual representations created by the students.

The first example of how the students supported one another in the process of making procedural decisions comes from Child 13. As Child 13 was describing how his/her group set up their data table for their leaf investigation, he/she continuously made reference to "what we did." This continued reference to “we,” referring to his/her lab partners and him/herself, indicates that the group was making decisions as a collective body. An excerpt from the transcript for Child 13 also shows that the student explicitly stated that his/her group was making decisions as a cohesive unit.

> T: Excellent! And, how did you decide to organize it on a chart rather than to use a separate page for each one?
>
> S: I thought that it would take up too much space to do it on separate pages, so I just did one. And, that is what the group decided.

Further evidence of this ongoing support of the learning community for Child 13 is shown in Figure 8. Figure 8 shows the chart, or data table, referred to in the preceding transcript. This is the chart that was developed by this group to record their data.

Although incomplete, this chart shows that the group had decided that their inquiry process would involve taking pictures of each leaf, finding the mass, making a leaf rubbing, drawing a diagram, counting the number of veins in the leaf, using a hand lens to look closely at the leaf, and finding the area of the leaf. The group had also made the decisions to record the data for all three of their samples on one page.

Figure 8: Data chart (child 13)

This data table was also reflective of the plan generated by this group prior to beginning their investigation. As Child 13 was working with his/her group, it was decided that they would use a camera to take pictures, use the triple beam balance to find the mass of each leaf, use crayons to make a leaf rubbing, use a pencil to do a drawing of the diagram, use a loupe to see the veins in the leaf, use a hand lens to look closely at the leaf, and use graph paper to find the area of the leaf (see Figure 9). It can be assumed that these decisions and that their overall investigative design were made by group consensus due to the continued referral to "we" throughout the transcripts of the student’s description of his/her multimodal representation.

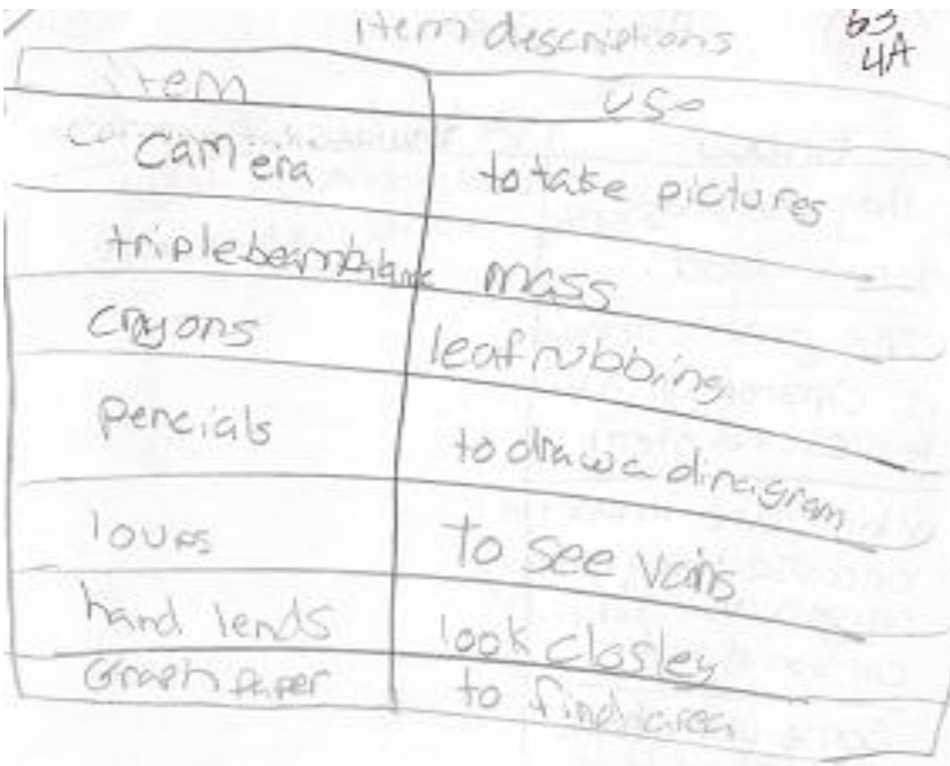


Figure 9: Investigative plan (child 13)

A comparison of the plan presented in Figure 9 and the data table found in Figure 8, also provide evidence that this group was working systematically through their data chart. Both the plan listed in Figure 9 and the organization of the data table in Figure 8 have the type of qualitative and quantitative observations to be made in the same order. Based on the portions of the data table that were completed and on the additional pages in this particular student's logbook, it can also be assumed that the students in this group were completing all of the observations for leaf one before moving onto their observations for leaf two and three. The pictures and the leaf rubbings for leaves being observed did not fit on the chart created by the students so they were recorded on subsequent pages in the logbook. The overall plan and procedure provide evidence that the students followed the same systematic organization throughout their inquiry process. This precise and careful adherence to the procedure by Child 13's lab group, gives further evidence that the student's participation in the Discourse of science, his/her meaning-making, and the way he/she was representing or communicating that meaning had been supported by the overall learning community of the science lab.

Each of the learning communities also provided a level of linguistic support for the students. An example from Child Three best illustrated how the students in the science lab had formed a learning community that provided this type of support. As Child Three was going through his/her logbook, he/she would occasionally pause briefly to ask his/her teammates how to translate a word from Spanish into English. An example of this transaction is shown in the transcript that follows as the student is describing how he/she designed the cover for his/her leaf and seed investigation. A picture of the cover the student is describing can be seen in Figure 10.

T: Tell me about what you put on your cover.

S: I put on my cover, flowers.

T: I like them. And, they look like they are all kinds of different flowers. Do you know what kinds of flowers they are?

S: A rose (points to the middle flower)

T: Beautiful!

S: A bluebonnet (points to the flower on the right), and…(pauses to ask her lab partner how to say the third flower in English)…sunflower (points to the flower on the left).

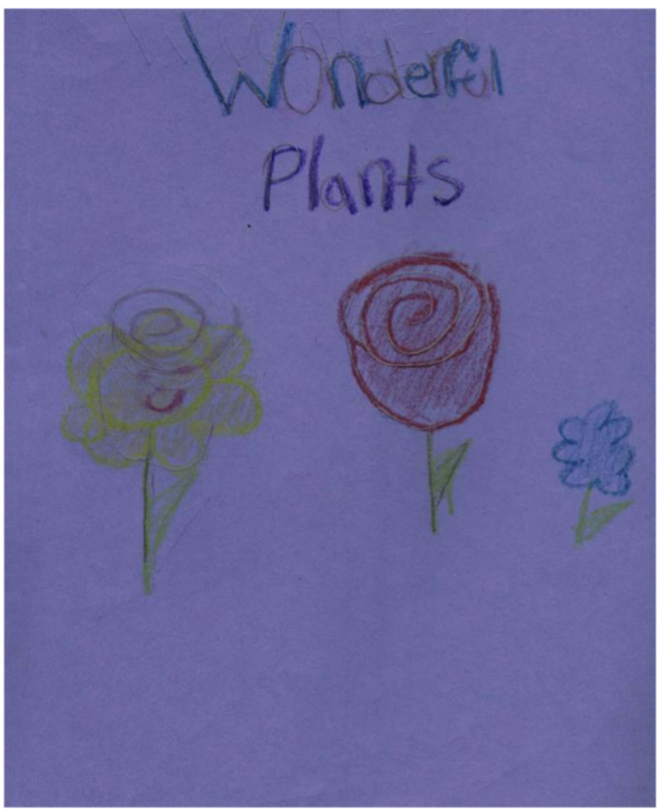
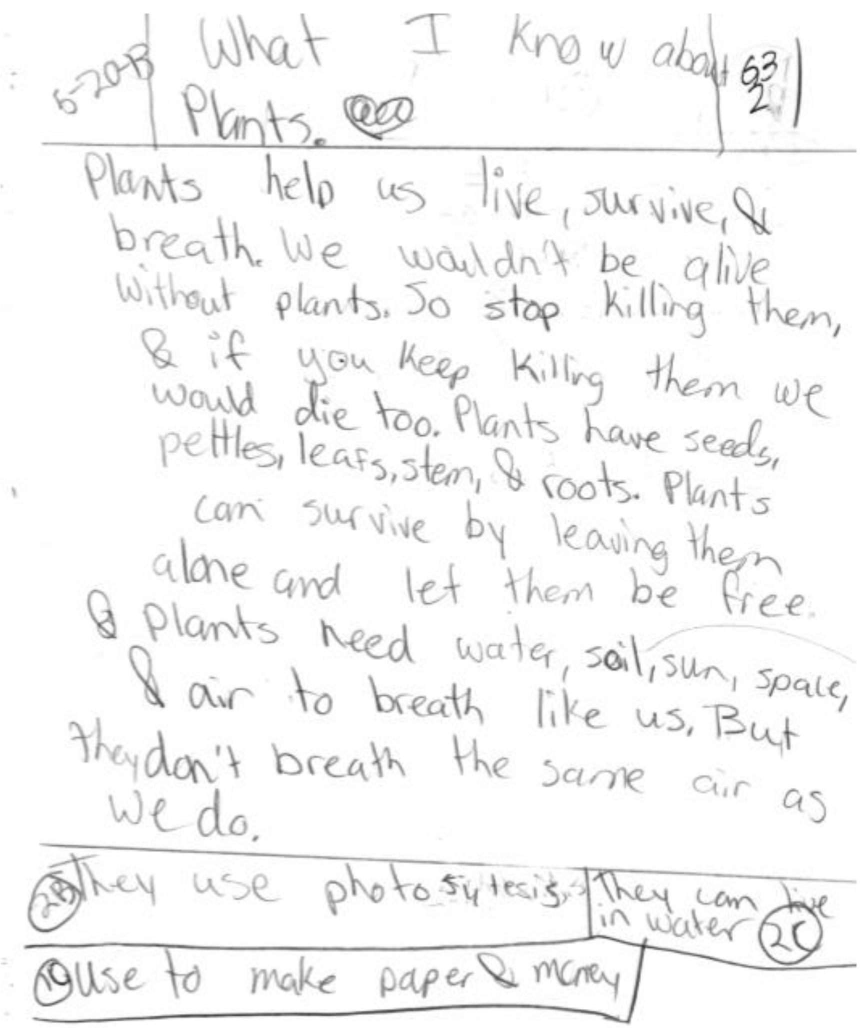


Figure 10: Logbook cover (child 3)

As an English language learner, Child Three's learning in the science lab, and his/her ability to participate in the Discourse of science, to make meaning, and to represent this meaning were directly supported by his/her fellow classmates. Many of the students in our school are bilingual and there is often constant code-switching between Spanish and English to help support those who are still learning the English language. Without this support from the learning community, many of these students would be unable to participate or understand the level of inquiry the students are asked to engage in as part of the normal curriculum in our school district.

Another example of linguistic support occurred for both bilingual and non-bilingual students alike. Many of the students often help one another with academic language as a natural part of their inquiry process. There is often a constant and reciprocal exchange of vocabulary and conceptual knowledge between the team members of each learning community. They rely strongly on one another and often do so as part of the natural conversation patterns of the inquiry process. In a sense, they scaffold one another's learning. This type of linguistic support is provided on a regular basis verbally, but can be seen specifically in the background information section of the students' logbooks for this particular investigation (see an example from Child 14's logbook in Figure 11*)*. In this example, the student had recorded a lot of information about what he/she already knew about plants. In the bottom section of the student's logbook, however, he/she added that plants use "photosynthesis." The student obtained this concept and the use of the academic word for how the plant produces their own food by using energy from the Sun from a student identified as 2B. In this example, we can see the meaning being made by the student and how that meaning is supported by his/her fellow teammates. This meaning was recorded in the student's logbook and recognition to the person providing the support is given.



5-20-08 What I know about Plants.

Plants help us live, survive, & breath. We wouldn't be alive without plants. So stop killing them, & if you keep killing them we would die too. Plants have seeds, pettles, leafs, stem, & roots. Plants can survive by leaving them alone and let them be free. & Plants need water, soil, sun, space, & air to breath like us. But they don't breath the same air as we do.

2B They use photosyntesis. They can live in water 2C

1B Use to make paper & money

Figure 11: Background information (child 14)

These previous examples show that the students in the science lab were not only part of a true learning community, but that this learning community was representative of the larger scientific community and its associated Discourse. The students regularly support one another in the literacies and practices of science conceptually, procedurally, and linguistically. They create an environment that is supportive, collaborative, and that allows each person to be responsible for the success of the community.

Theme Two: Making Qualitative Observations and Quantitative Measurements

The second overarching theme that emerged from the data during this investigation illustrates that the students were able to participate in the Discourse of science, create meaning and communicate their scientific understandings in appropriate ways by making qualitative observations and quantitative measurements during the inquiry process. In this research study, the multimodal textual representations created by the students demonstrated that students: (a) used scientific tools and field guides to make qualitative and quantitative observations; (b) had a growing understanding that scientists use the metric system to make quantitative measurements; and (c) possessed a developing realization that measurements must be repeated multiple times for reliability. All of these aspects of making observations were essential elements of participating in the Discourse of science, making-meaning, and representing this meaning in meaningful ways to the larger scientific community.

In the discipline of science, student scientists often learn how to participate in the Discourse of science by participating in the practices and literacies of science first-hand.

This experience allows them to actively engage in an authentic style of meaning-making. Students often learn how to think and act like scientists by "doing" and "speaking" science. They are apprenticed into this new way of being (Lemke, 1990; Gee, 1990). In the student logbooks examined for this study, evidence of this progressive development was seen by looking at the observations and measurements made by the students. Their logbooks were reflective of this process because they showed how the students selected scientific tools, thought about how each tool needed to be used, made observations using the appropriate tool, and recorded these observations in their logbook as multimodal representations. The selection of tools and identification of how each tool could be best used to gather data was seen in the investigation plan developed by the students. These plans incorporated tools that allowed for both qualitative and quantitative observations. An example of a research plan provided by Child 13 and Child Five are provided in Figure 12 and Figure 13. In Figure 12, Child 13 has listed his/her investigation plan as a list of "item descriptions". Using a t-chart to organize his/her investigation allowed the student to list not only to tools that the student's group had decided to use, but how they planned on using each tool in the data collection process. The investigation plan included a combination of tools that would be able to help the student make both qualitative and quantitative observations. Child Five's investigative plan (seen in Figure 13) provided a similar example. Child Five, however, chooses to make a list of what his/her group planned on doing during their investigation. Many of the tools and their purposes were provided, but Child Five did not provide a complete list of every tool and its use. Both examples, however, provided an example of how the students were able to use scientific inquiry as a means of engaging in the Discourse of science by establishing a plan to make both qualitative and quantitative observations.

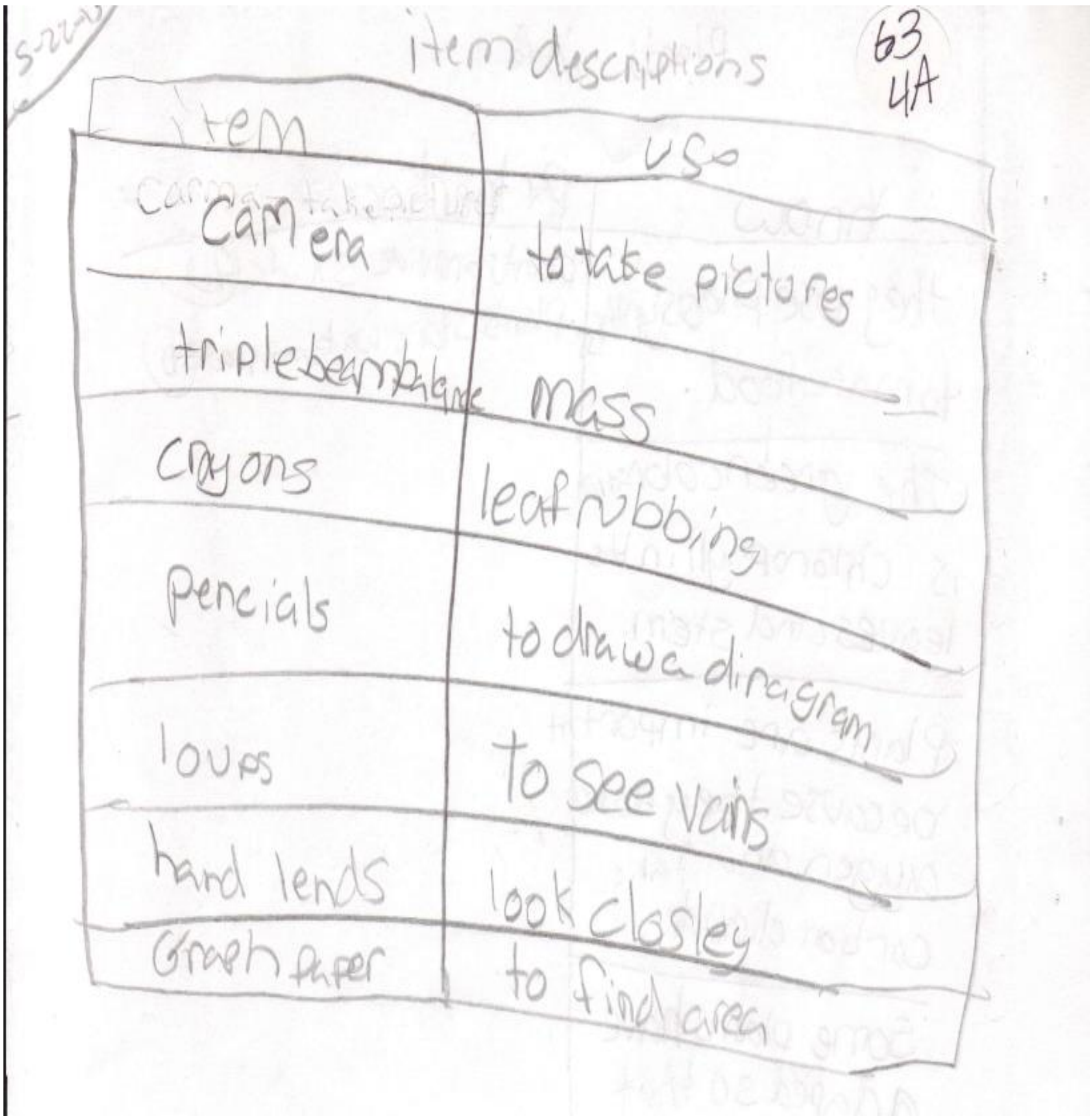


Figure 12: Plan for inquiry including both qualitative and quantitative observations (child 13)

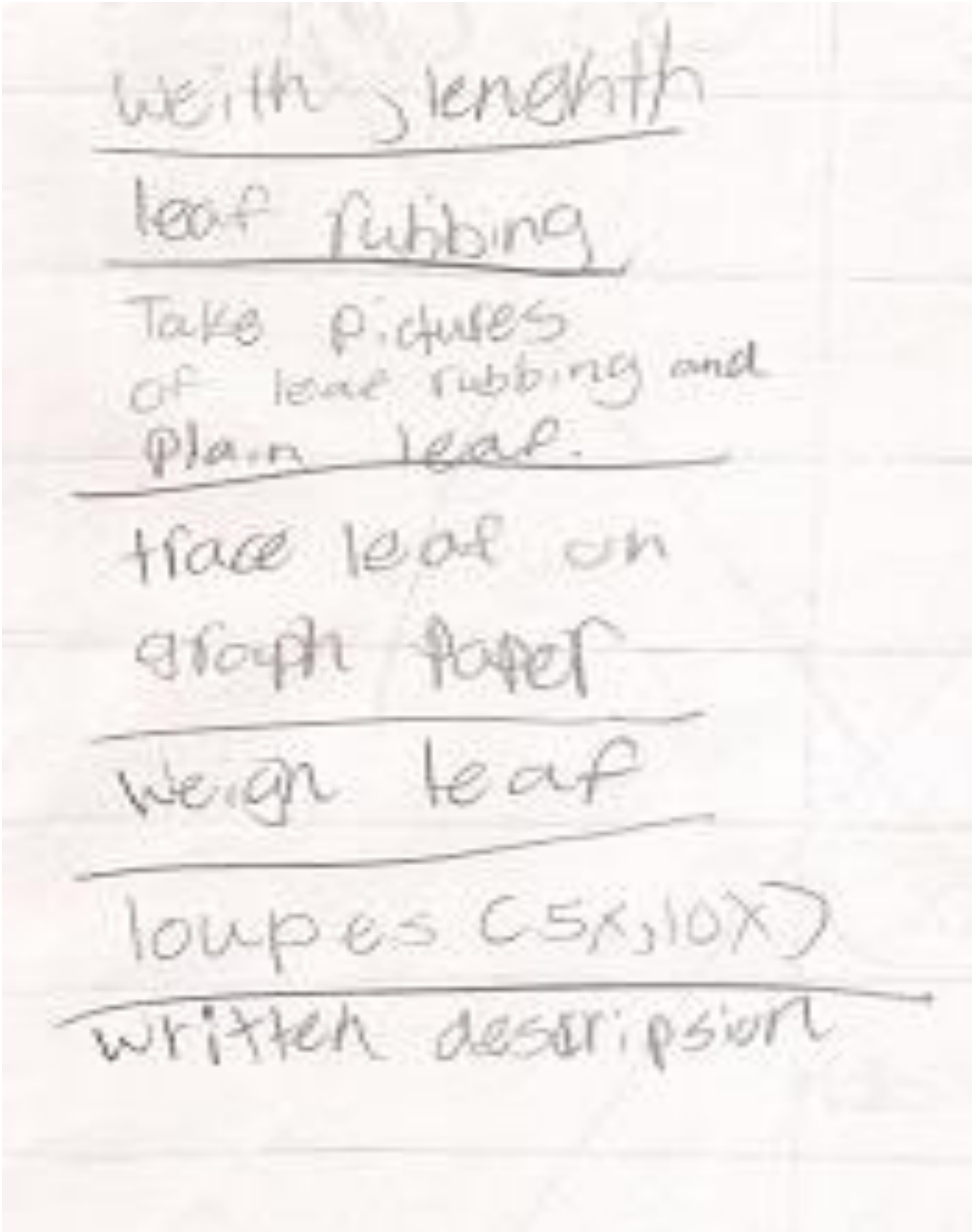


Figure 13: Plan for inquiry including both qualitative and quantitative observations

Further evidence for how students participate in the Discourse of science by making qualitative and quantitative measurements was also seen when looking directly at the data collected by the students during their process of inquiry. The examples found in Figures 14, 15 and 16 show the data recorded in three different formats. Even though the presentation of the data varied from student to student, it is important to note that all three samples show students were engaged in the Discourse of science by making both qualitative and quantitative measurements, how they were creating meaning during this observation process, and how they were representing their data using organizational tools.

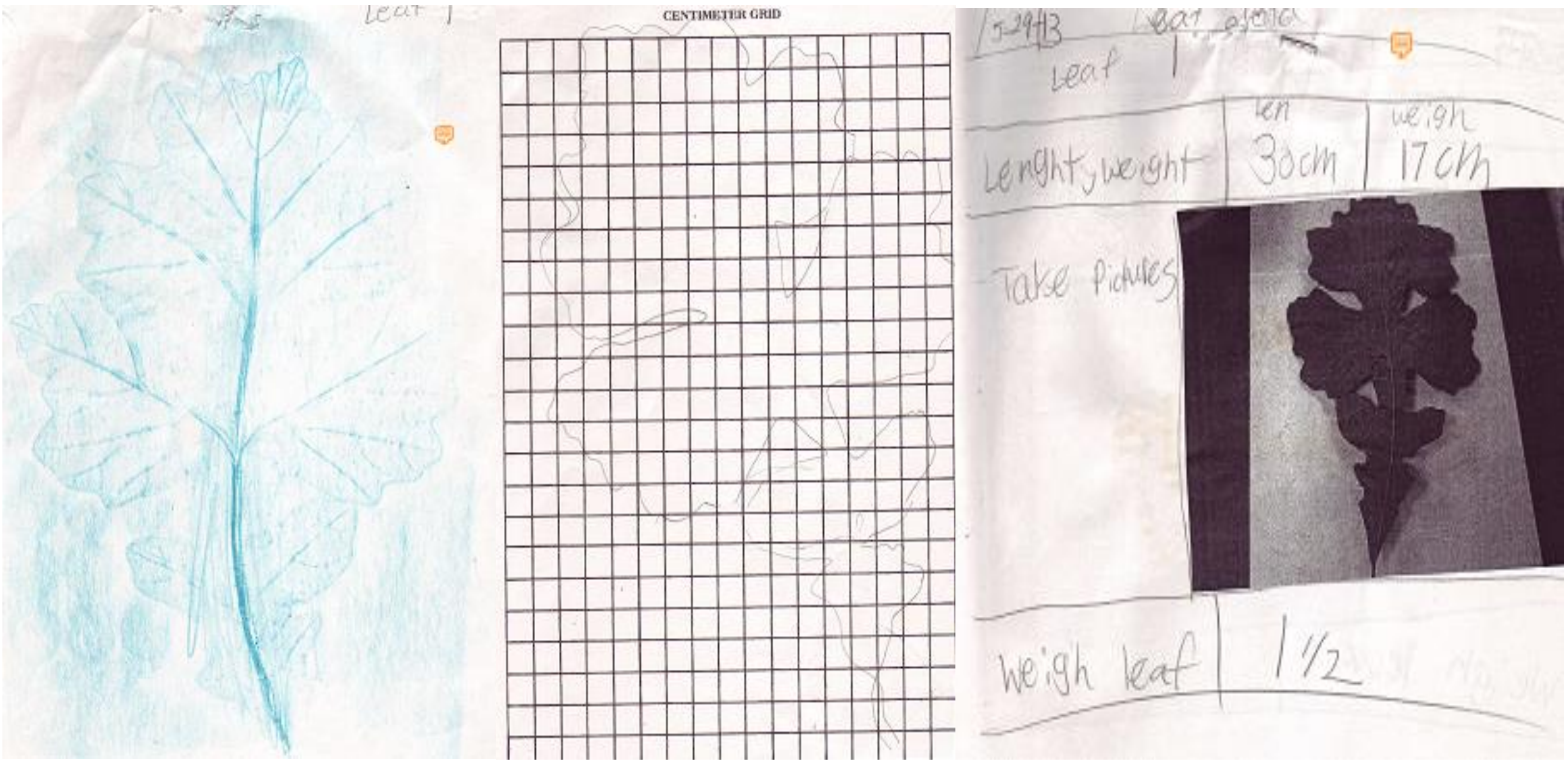


Figure 14: Qualitative and quantitative data collected during leaf investigation (child five)

Figure 15: Qualitative and quantitative data collected during leaf investigation (child six)

Figure 16: Qualitative and quantitative data collected during seed investigation (child 11)

During the observation process, students also illustrated their use of the literacies of science and meaning-making by utilizing the field guides provided to help them make more descriptive qualitative observations of the leaves. This process was only mildly familiar to the students and no instruction was provided as to how to use the field guides. Some groups decided to use them and others disregarded them completely. Those students who did choose to identify parts of their leaves using the field guide provided evidence of how the students used these guides to support their own conceptual development as well as illustrated their developing ability to engage in the classificatory practices of science common to those in the larger scientific community. An example from Child 12 is provided in Figure 17 to show one example of how these field guides were implemented by the students. In this particular example, the students in Child 12's group used the field guides to identify the leaf shape, the formation of the leaf veins, the leaf structure, and the leaf margin for each of their samples. Although, all of the leaves chosen by this group for their investigation were similar, this sample still exemplifies how this group adhered to the standards of the discipline of science by using the field guides to describe and classify their examples correctly. The process represented in this text illustrates both their participation in the Discourse of science and their meaning-making process itself.

Figure 17: Data collected with the help of field guides (child 12)

Another indication of the student's ability to communicate and represent meaning in ways appropriate for the larger scientific community was represented by their usage of metric units when making quantitative observations. Many students, as demonstrated in the examples that follow (see Figures 18, 19, and 20*)*, have mastered this understanding, but a few students still continued to switch between metric and customary units, especially when customary measurements were being taught in their math classes subsequently as was the case during this investigation. It is important to note, that measuring in metric units is just one step toward providing detailed and accurate measurements which are standard in the discipline.

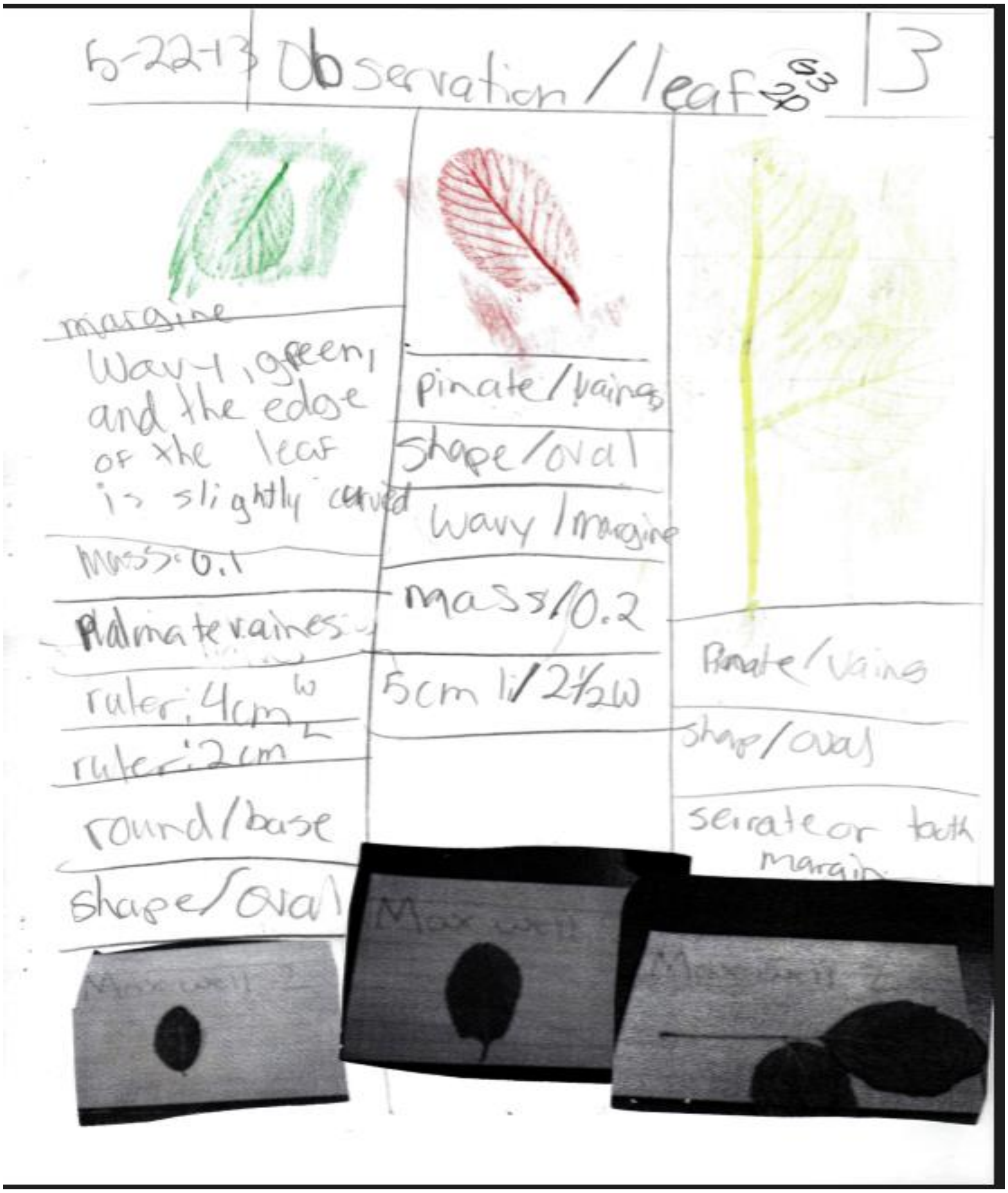


Figure 18: Example of metric units used on a data table for leaf observations (child 14)

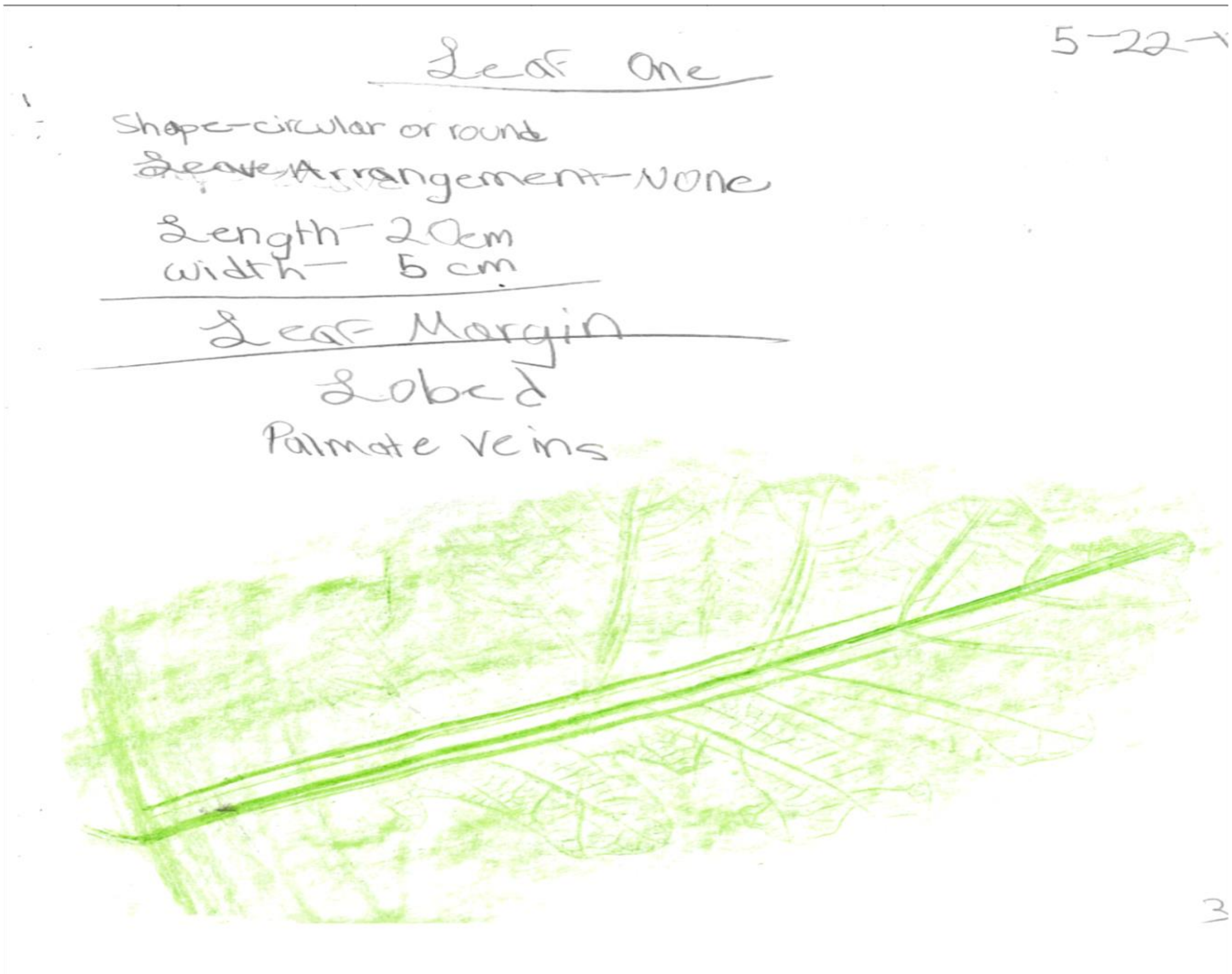


Figure 19: Example of metric units used on a data table for leaf observations (child 3)

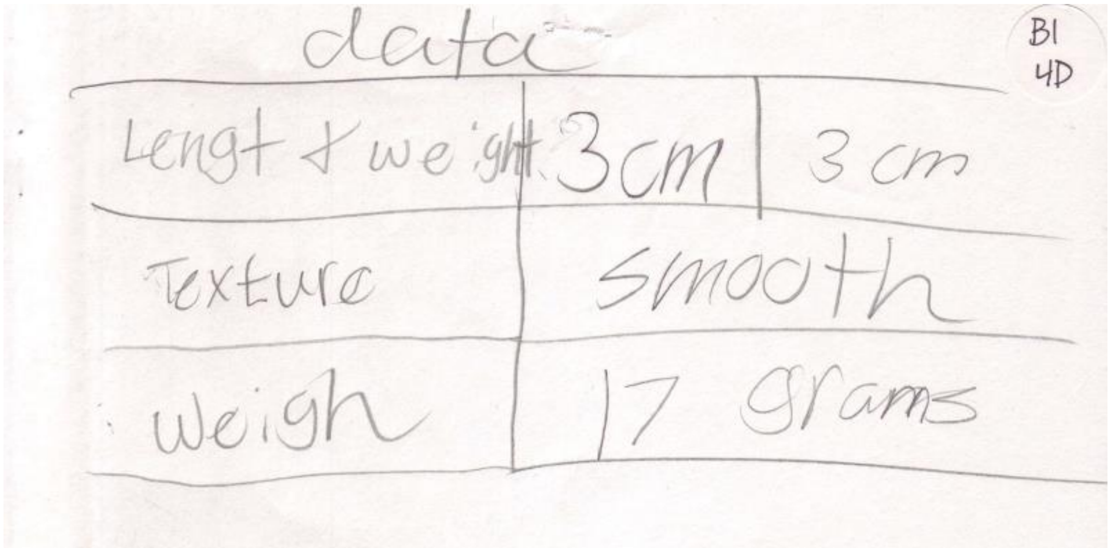
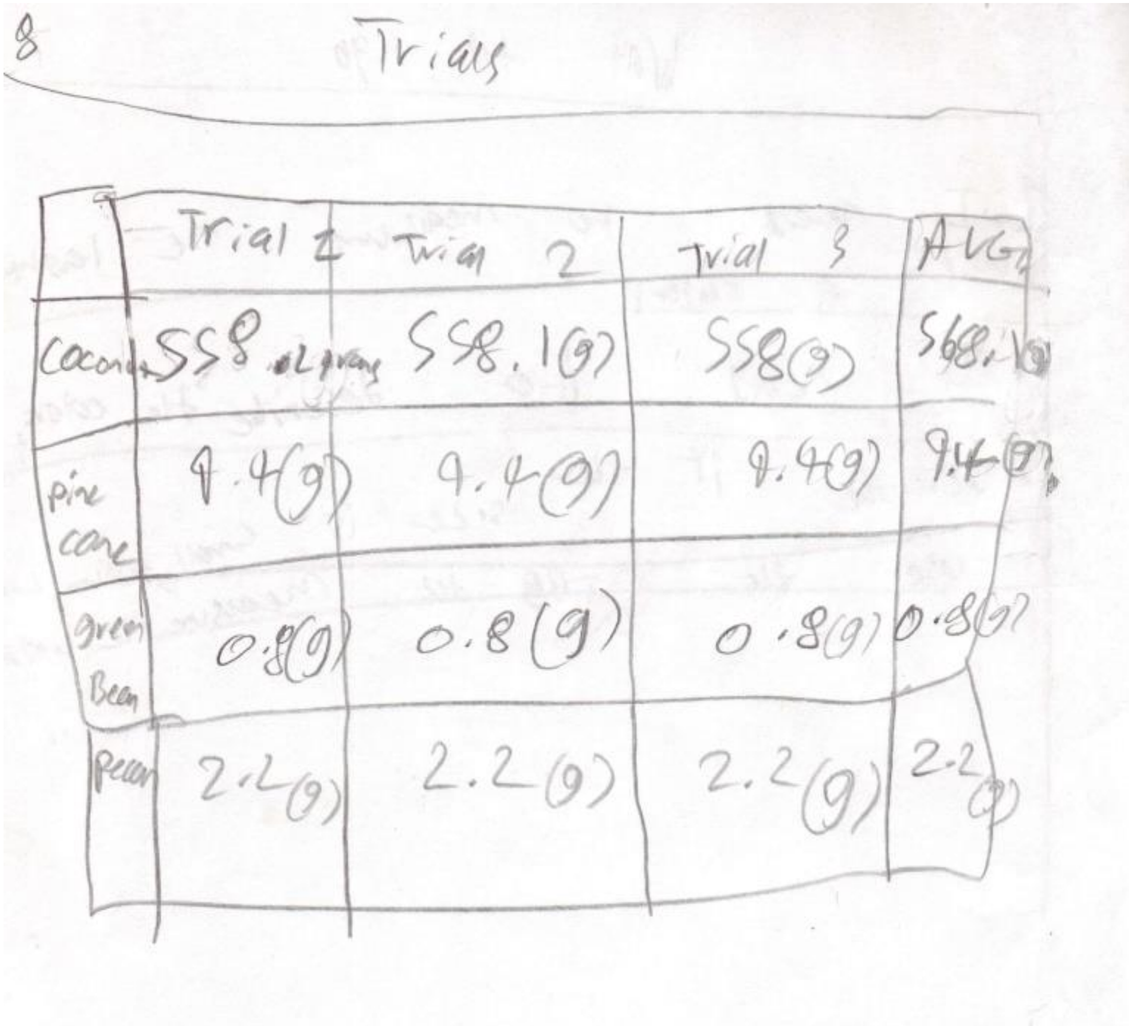


Figure 20: Example of metric units used on a data table for leaf observations (child five)

While metric units were utilized in the three examples provided in Figures 18, 19, and 20, there was a varying degree of accuracy in the actual use of the measurement tools seen in not only these examples, but in all of the student examples from this research study. For example, the triple beam balance, which was used to measure mass, and the metric rulers provided in the science lab are both able to measure to the nearest tenth of a unit. Much inconsistency in the accuracy of the measurements conducted by the students existed. Figure 21 provides an example of student who had correctly used the triple beam balance to measure four seeds to the nearest tenth of a gram. This student understood how to accurately use the triple beam balance to obtain correct measurements.


8 Trials

	Trial 1	Trial 2	Trial 3	AVG.
Coconut	558	558.1(g)	558(g)	568.1(g)
pine cone	9.4(g)	9.4(g)	9.4(g)	9.4(g)
green Bean	0.8(g)	0.8(g)	0.8(g)	0.8(g)
pecan	2.2(g)	2.2(g)	2.2(g)	2.2(g)

Figure 21: Correct use of a triple beam balance recorded on seed data table (child 1)

Some students had more difficulty making accurate measurements. Many of them rounded their data to the nearest whole unit, while others added an extra place value unit to their number or recorded their measurement as a fraction rather than in the more customary decimal form (see Figures 22, 23, 24 and 25). Figure 22, specifically shows how the student's measurement using the metric ruler were rounded to the nearest whole centimeter rather than to the nearest tenth of a centimeter. The measurement for mass made by this student also provides an example of how a few of the students would also occasionally use a fraction instead of a decimal to represent part of a unit. Child Six (see Figure 23) provided a similar example of how the students rounded their numbers to the nearest whole and represented partial units utilizing fractions. An example of adding an extra place value unit was seen in the work of Child 13 (see Figure 24*)*. This student had calculated the mass of leaf one as two hundredths of a gram when the triple beam balance was only able to measure to the nearest tenth. A final example from Child 15 showed how a few of the students switched between metric and customary units of measurement (see Figure 25*)*. The range of variation in these examples suggests a developing understanding of the ability to make accurate and detailed quantitative measurements. Learning how to make these measurements is part of learning the literacies of science that allow a student to participate in scientific Discourse.

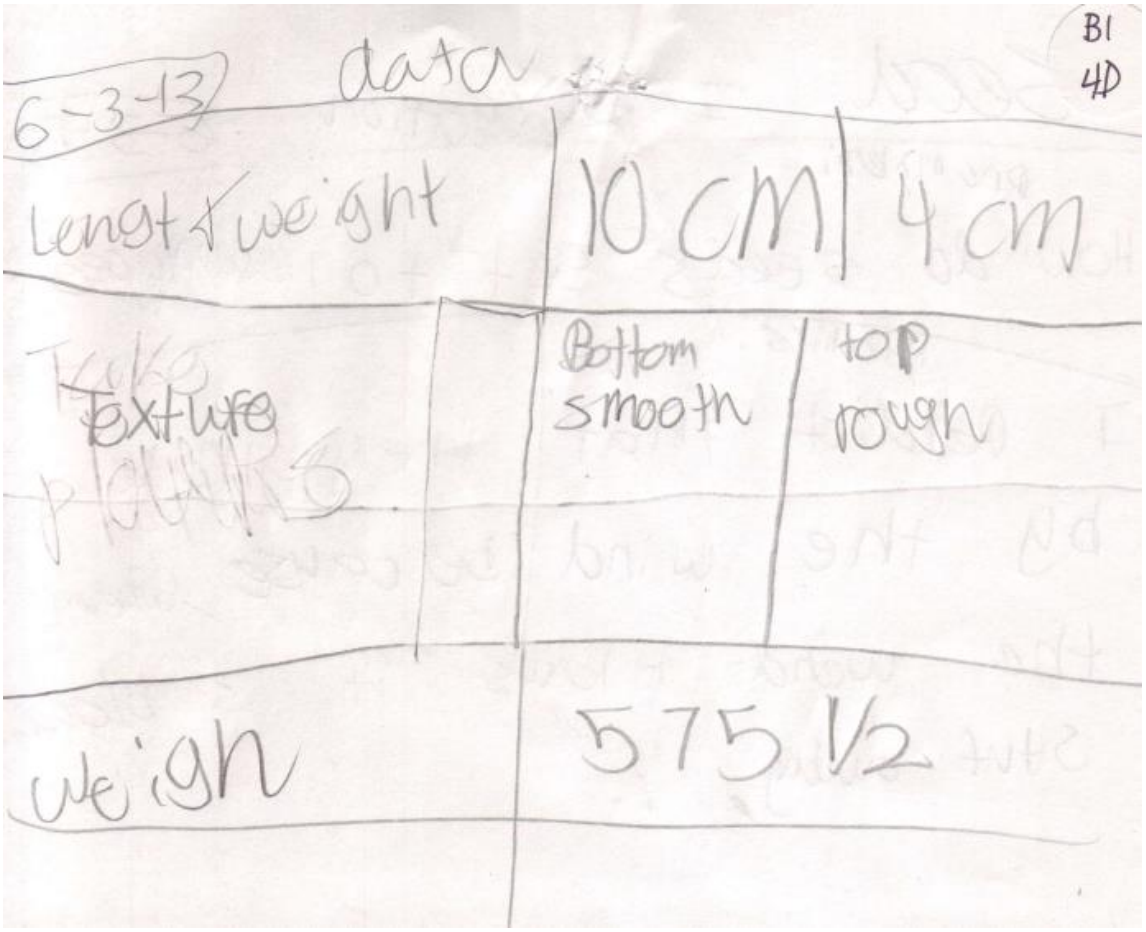


Figure 22: Example of rounding units to the nearest whole number and the use of fractions in quantitative measurements (child five)

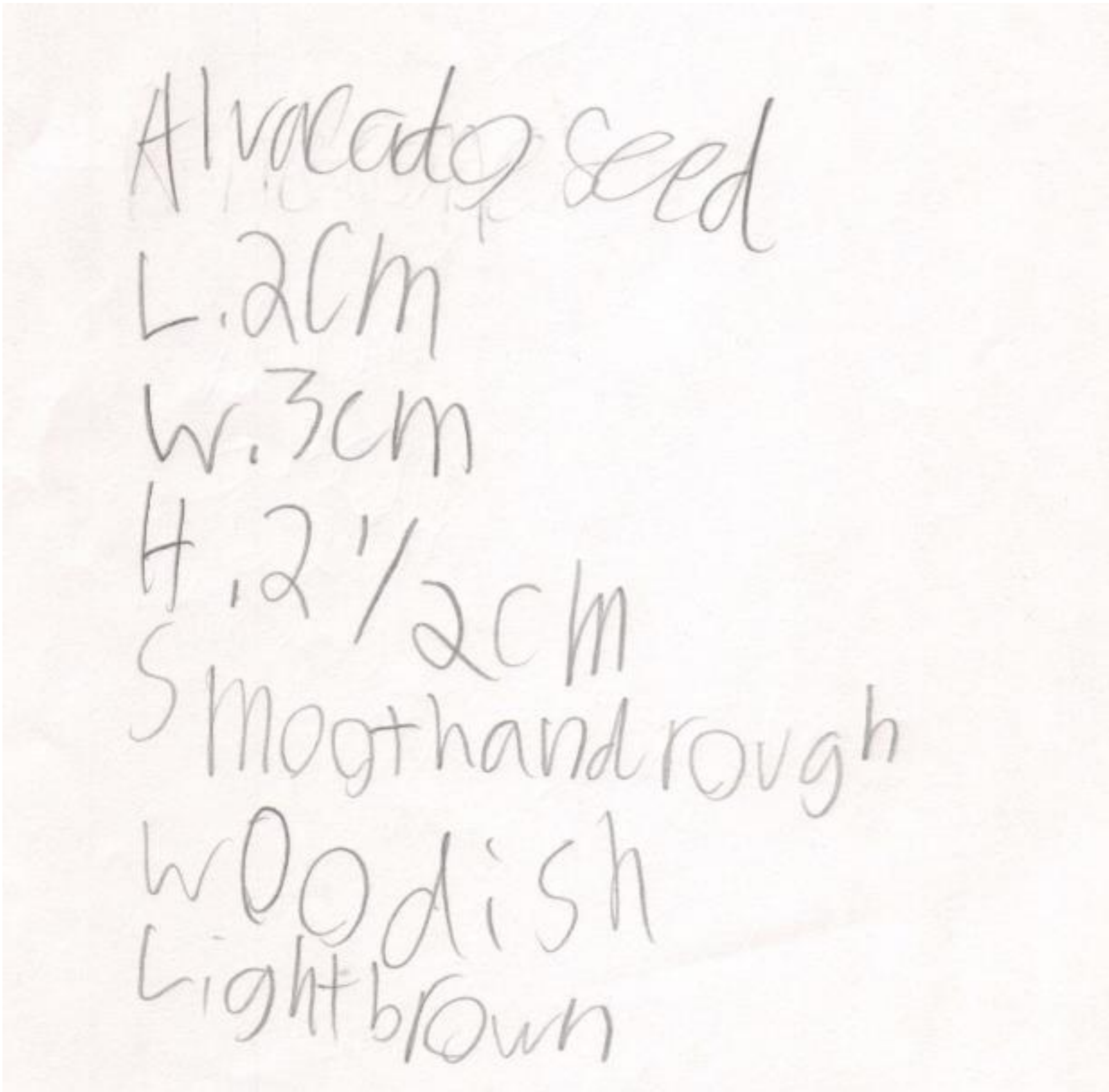
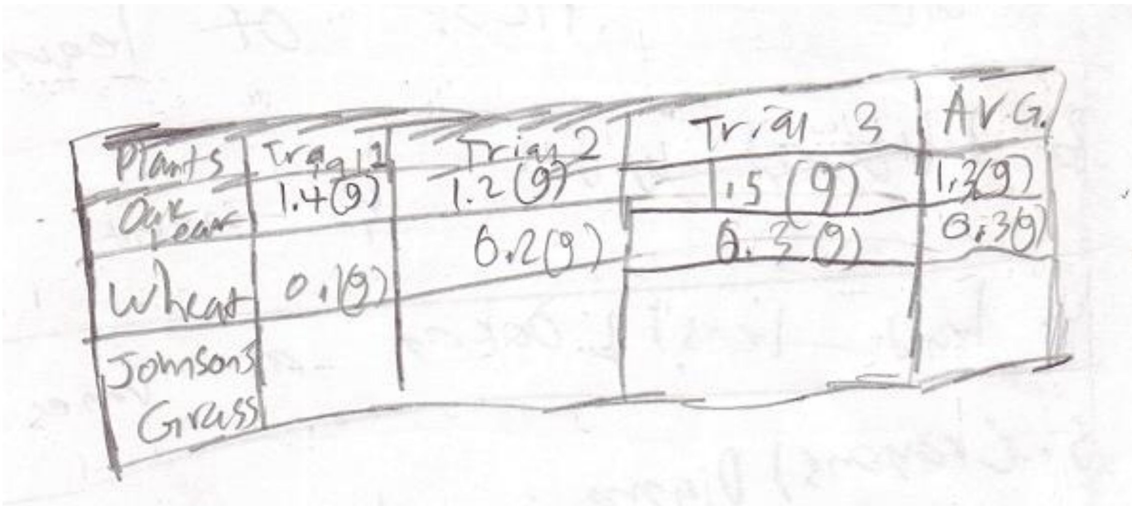


Figure 23: Example of rounding units to the nearest whole number and the use of fractions in quantitative measurements (child six)

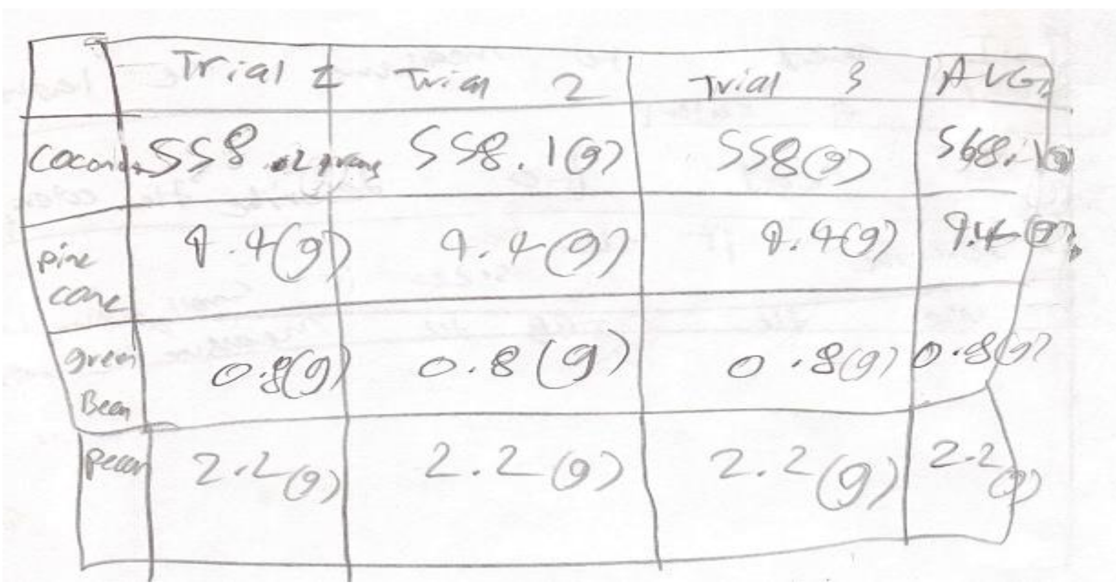
Figure 24: Example of an additional place value unit added to the quantitative measurement for mass (child 13)

Figure 25: Example of switching between metric and customary units of measurements (child 15)

A final example of the students' ability to participate in scientific Discourse, make-meaning, and create textual representations to communicate their scientific understanding was also illustrated by the data. It was seen in the student's usage of repeated trails during their inquiry process. Repeated trials are often used by scientists to increase the reliability of their research. Child One and Child 11 both specifically referred to this idea of repeating trials. In the case of Child One (see Figure 26), both his/her leaf observation data and seed observation data have used repeated trials correctly and show an understanding of how to not only conduct repeated trials during an investigation, but also how to analyze the data by finding the average of the trials. Figures 27 and 28, show a developing understanding of this same concept. Child 11 has utilized the word trials in Figure 27 to show that he/she is repeating his/her investigation multiple times using different leaves, but this example illustrated only a partial understanding. Trials should be repeated with the exact same sample the exact same way multiple times to ensure that the test results are reliable. In the subsequent investigation on seeds, Child 11 realized that using the word trial was not the correct way to label each column for the multiple samples he/she was investigating and instead replaced the word trial with the words seed one, seed two, and seed three (see Figure 28), which was a more appropriate designation within the scientific discipline. Although using the word trial incorrectly, this student's misapplication of the word was indicative of his/her growing understanding of the Discourse of science both in how to use repeated trials to increase the reliability of the study and in how to correctly designate the samples being studied during an investigation. In this example we were given a momentary glimpse into the meaning-making process of the student.



Plants	Trial 1	Trial 2	Trial 3	AVG.
Oak Leaf	1.4(g)	1.2(g)	1.5(g)	1.3(g)
Wheat	0.1(g)	0.2(g)	0.3(g)	0.3(g)
Johnsons Grass				



	Trial 1	Trial 2	Trial 3	AVG
coconut	558 .2 grams	558.1(g)	558(g)	568.1(g)
pine cone	9.4(g)	9.4(g)	9.4(g)	9.4(g)
green Bean	0.8(g)	0.8(g)	0.8(g)	0.8(g)
pecan	2.2(g)	2.2(g)	2.2(g)	2.2(g)

Figure 26: Data tables showing repeated trials (Child 1)

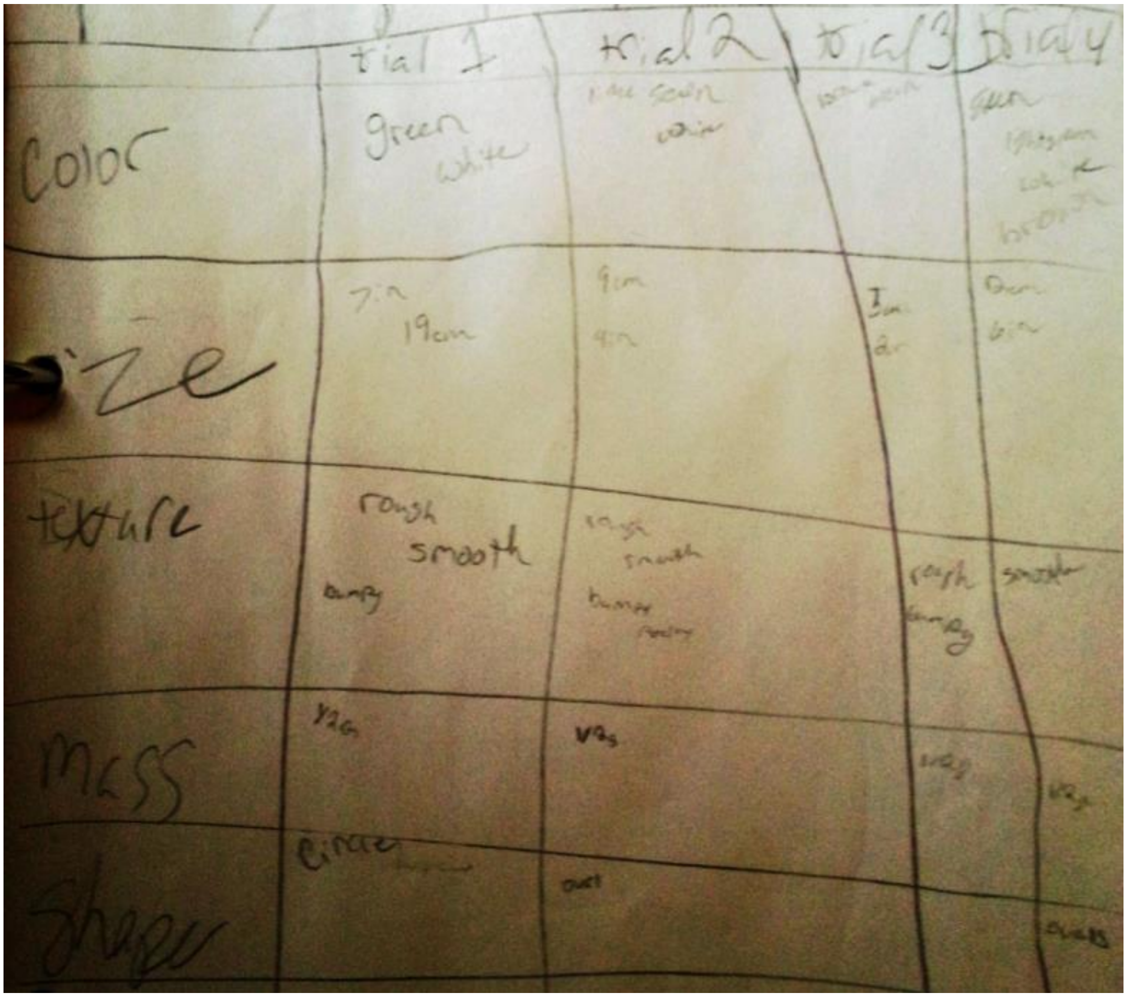


Figure 27: Data table showing repeated trials (child 11)

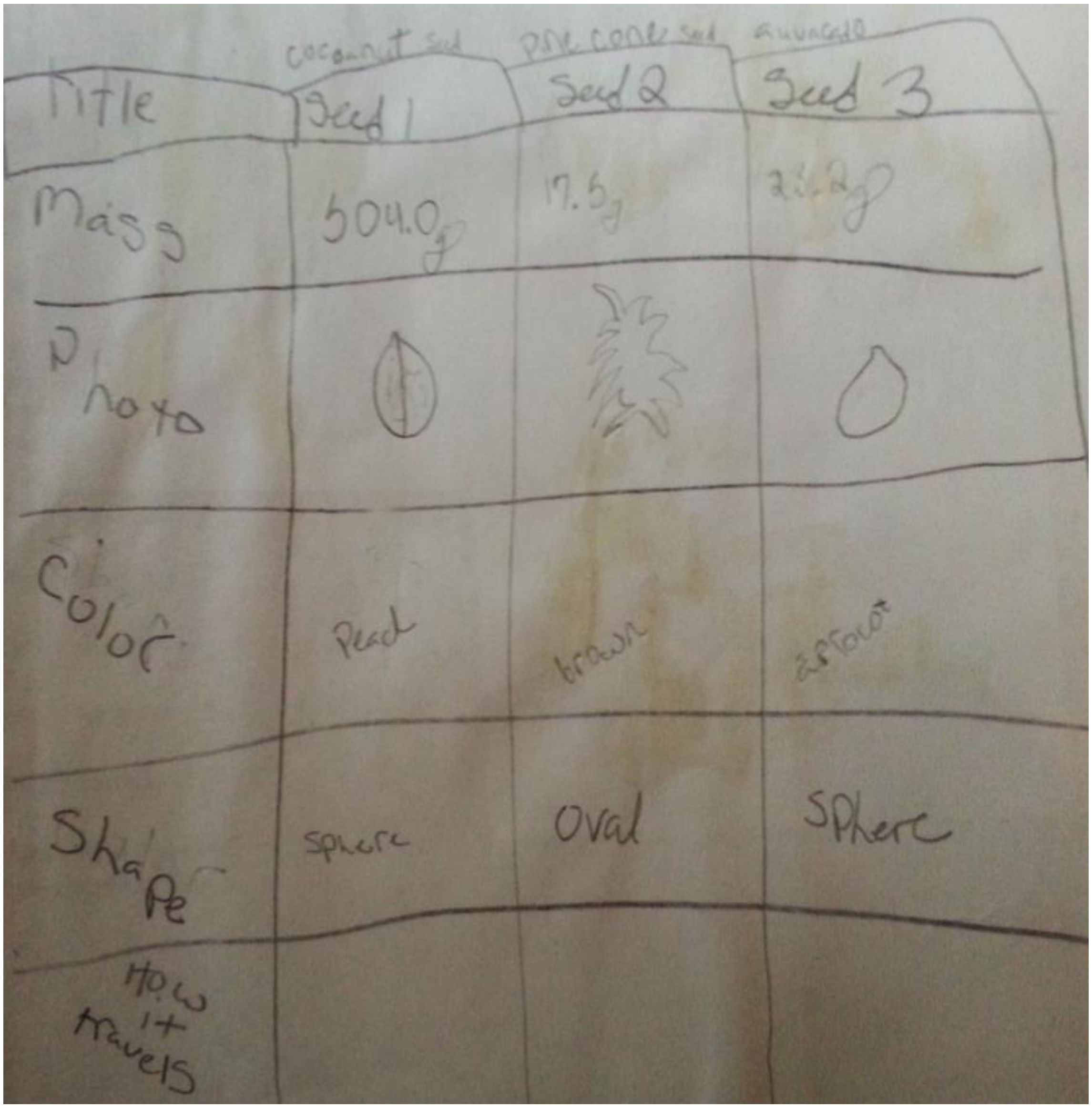


Figure 28: Data table showing a transition in heading categories from trials (seen in figure 27) to appropriate designation of samples (Child 11)

By examining the way students make and represent their qualitative observations and quantitative measurements, we were able to see part of the students' development as student scientists. Their ability to use scientific tools to make precise and accurate observations is a skill central to one's ability to participate in the Discourse of science. As the students continue to develop their understanding of this process by actively engaging in making observations and measurements, they will continue to become more accurate and will represent their data in more clear and concise ways.

Theme Three: Use of Graphic Organizers

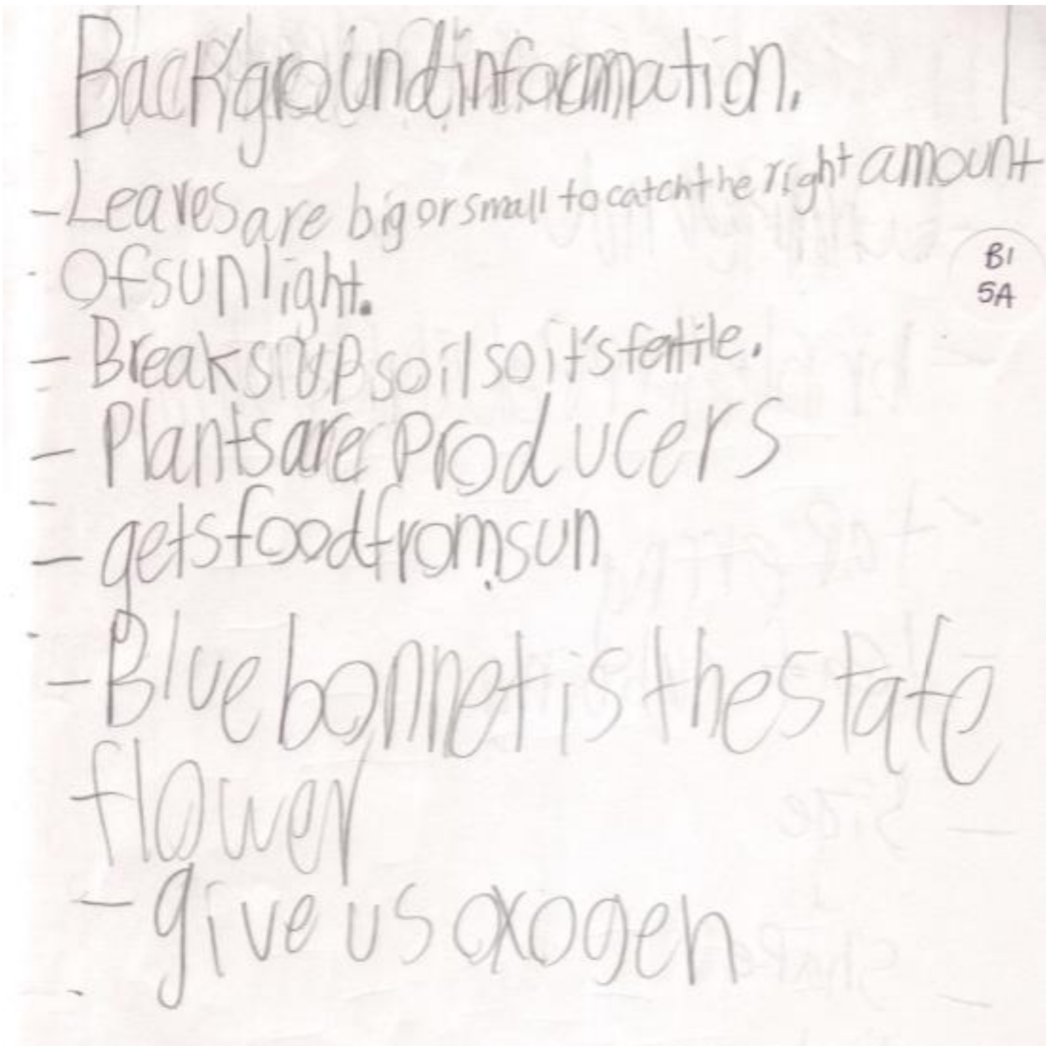
The third overarching theme arising from the data from this investigation looked at the organizational tools the students used to represent and communicate meaning. During scientific inquiry students often create multimodal representations using the literacies of science accepted by the larger scientific community of practice to represent their scientific understandings (Kozma & Russell, 1997). Their ability to represent scientific ideas competently and fluently is a skill that develops over time as they become more and more adept at the literacies and practices of science. As designers, students must select from the various semiotic modes and resources at their disposal. Their job is to find the most effective way to represent their scientific understanding to the larger scientific community. In the samples collected from the students, their developing understanding of how to best participate in the Discourse of science through the construction of multimodal representations was seen as they used graphic organizers to organize and represent their data from this inquiry investigation. Specifically, the examples from the students showed two things: (a) the students were able to utilize a wide variety of graphic organizers for various purposes to communicate scientific understanding; (b) and their organization and choices of how to best represent their data improved with experience. The first of these will be expounded in this section and the latter will be discussed in detail as part of the discussion for theme five.

During the inquiry process, the students used a wide variety of graphic organizers to meet their communicative and organizational needs. Among the graphic organizers selected by the students were lists, diagrams, t-charts, and tables. The student usage of these organizers were indicative of their understanding of the literacies of science and their participation in the larger Discourse of science that requires students to be able to collect, analyze, and communicate their scientific understanding in ways that are commonly used by the scientific community.

Lists

One of the most common organizational structures used by the students was a list. Students used lists to share what they knew about plants before beginning their investigation of leaves and seeds, in order to create procedures for their investigations, and to organize their data. Figures 29, 30, and 31 show an example of each of these types of list. Figure 29 shows an example of one student's knowledge about plants prior to beginning his/her leaf and seed investigations. His/her knowledge was recorded as a list of facts about plants. Both the organizing structure of the list and the academic vocabulary embedded in the list are exemplars of the student's participation in the

Discourse of science and of their developing literacies of science. This sample showed that the student knows how to communicate in a clear and concise manner as well as demonstrating the student's understanding of how to use appropriate scientific vocabulary to describe his/her knowledge.



Backgroundinformation.

-Leavesare big or small to catch the right amount

-ofsunlight.

-Breaks up soil so it's fertile.

-Plantsare Producers

-getsfoodfromsun

-Bluebonnet is thestate flower

-give us oxogen

B1 5A

Figure 29: Hyphenated list of what the student knew about plants before beginning the inquiry lesson (child six)

The second list provided in Figure 30 is an example of how lists were used to create procedures for their investigations. A list is a perfect organizing tool for writing a scientific procedure as procedures often follow a sequential order. Creating steps to follow establishes this sequence and was often used by the students to guide their investigation. In this particular sample, the student not only listed his/her steps, but he/she has also included many of the tools he/she was going to use during the inquiry process. Again, this demonstrated the students' participation in the Discourse of science. Students engaging in scientific Discourse must be able to plan and follow through with investigations, they must recognize that many procedures are sequential and must be repeated in the same way mulitlple times in order to obtain relaible data, and using an ordered list is an appropriate way to represent a procedure for an investigation.

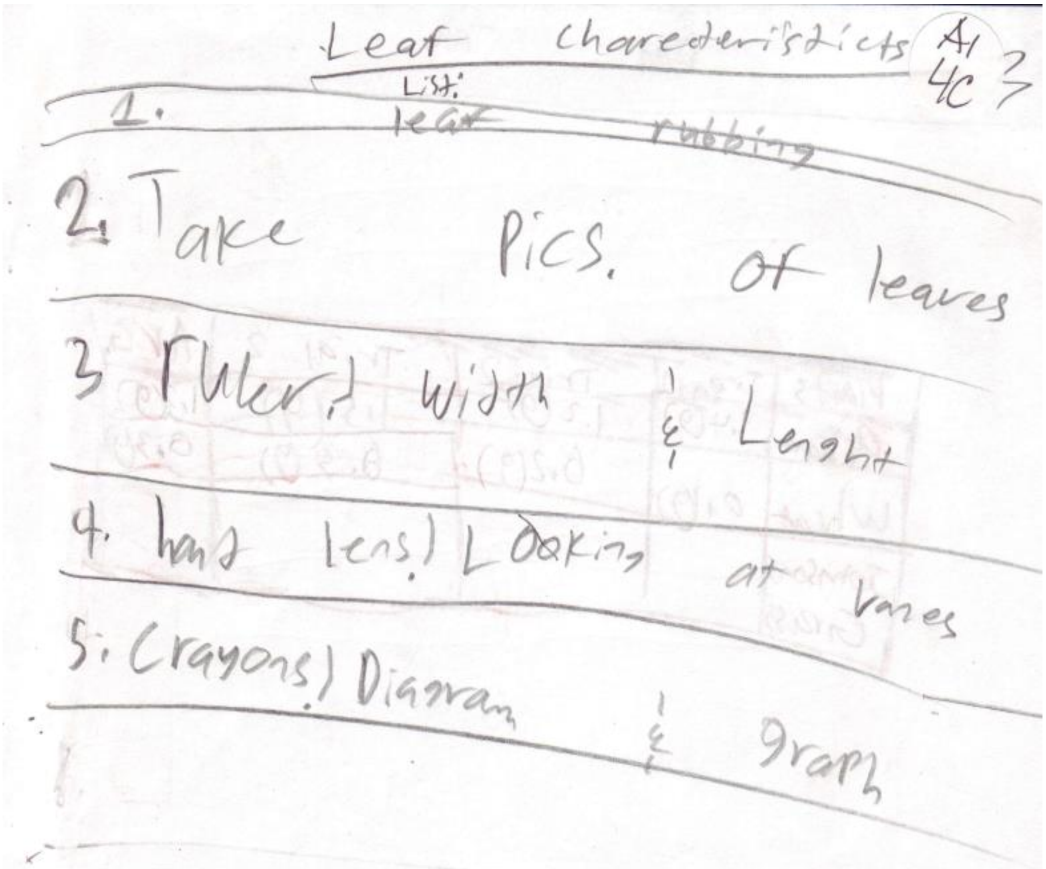
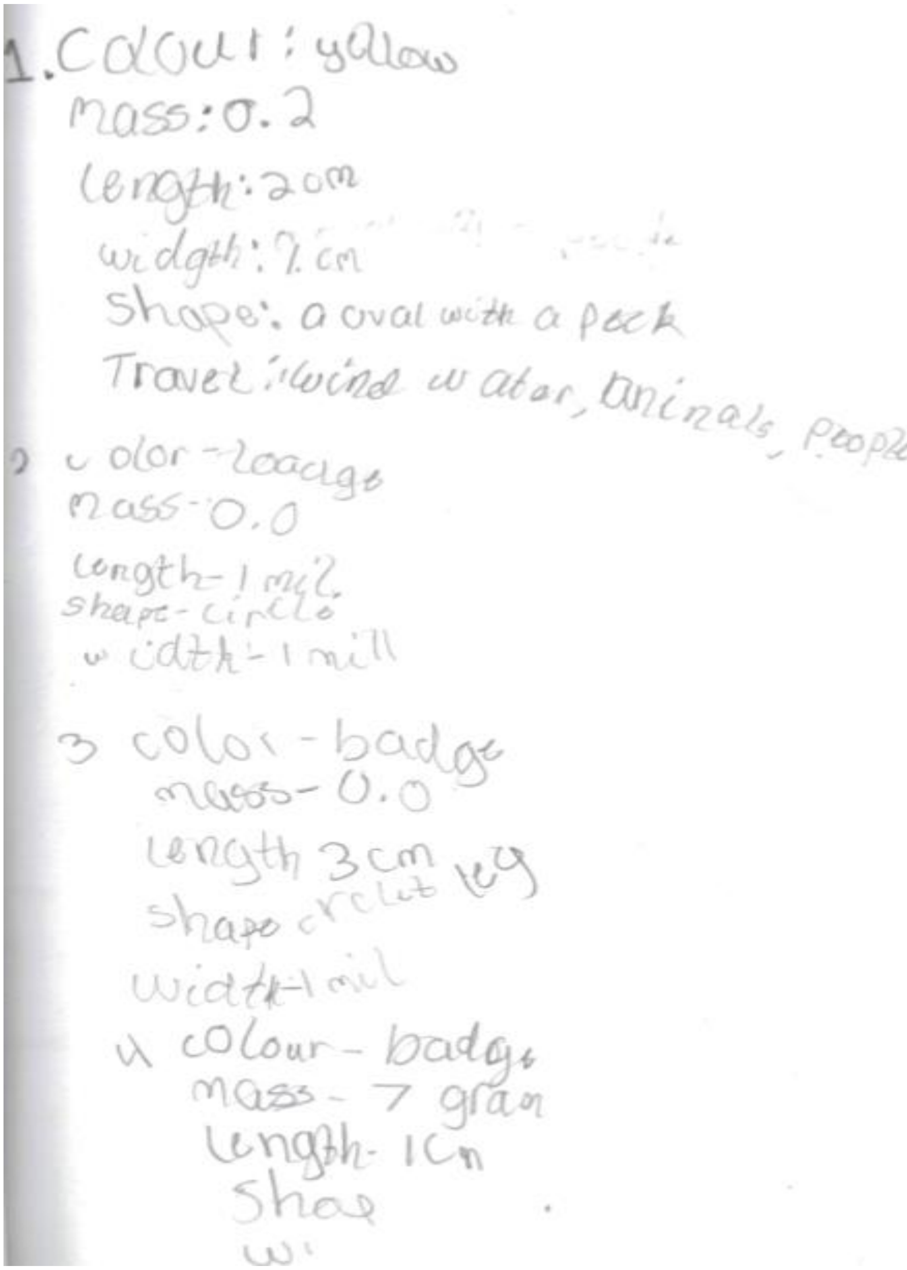


Figure 30: Numbered list of procedures for leaf investigation (child one)

A third way that students used lists during this investigation, was as a way to organize their data. Although, a data table might be a more standard way of organizing data collected during an investigation, the lists created by the students during this process often exhibited the sequential order of their research procedures. Figure 31 provides an example of a student who used a list to record his/her data for his/her seed investigation. With a few minor exceptions, the order in which the observations for each seed were made followed the same sequential pattern exhibiting that this student understood the orderly nature of a scientific procedure and as such was learning how to participate in the Discourse of science.



1. Colour: yellow
mass: 0.2
length: 2cm
widgth: 7 cm
Shape: a oval with a peck
Travel: wind water, animals, people
2 color - oaarge
mass - 0.0
length - 1 mil
shape - circle
width - 1 mill
3 color - badge
mass - 0.0
length 3cm
shape circle
width - 1 mil
4 colour - badge
mass - 7 gram
length - 1Cm
Shap
W

Figure 31: List of data from seed investigation (child ten)

Additional ways that lists were used to organize data during the inquiry lesson was seen in the examples provided in Figure 32 and 33. Figure 32 shows two pages from the logbook of Child Nine. In this example, the child has created a list of both his/her leaf rubbings and diagrams. The organization of the data provided in this example has both strengths and weaknesses. Although the student has used lines to separated, or delineated, each data sample, the order of observations made is inconsistent from one page to another. This example showed that the student understands that data must be organized, but he/she was still developing his/her understanding that the collection and organization of data should be conducted in a systematic order. As the student continues to develop his/her undertanding of the importance of following a set procedure he/she will be able to more fully participate in the Discourse of science and this will be reflected in the presentation of his/her data.

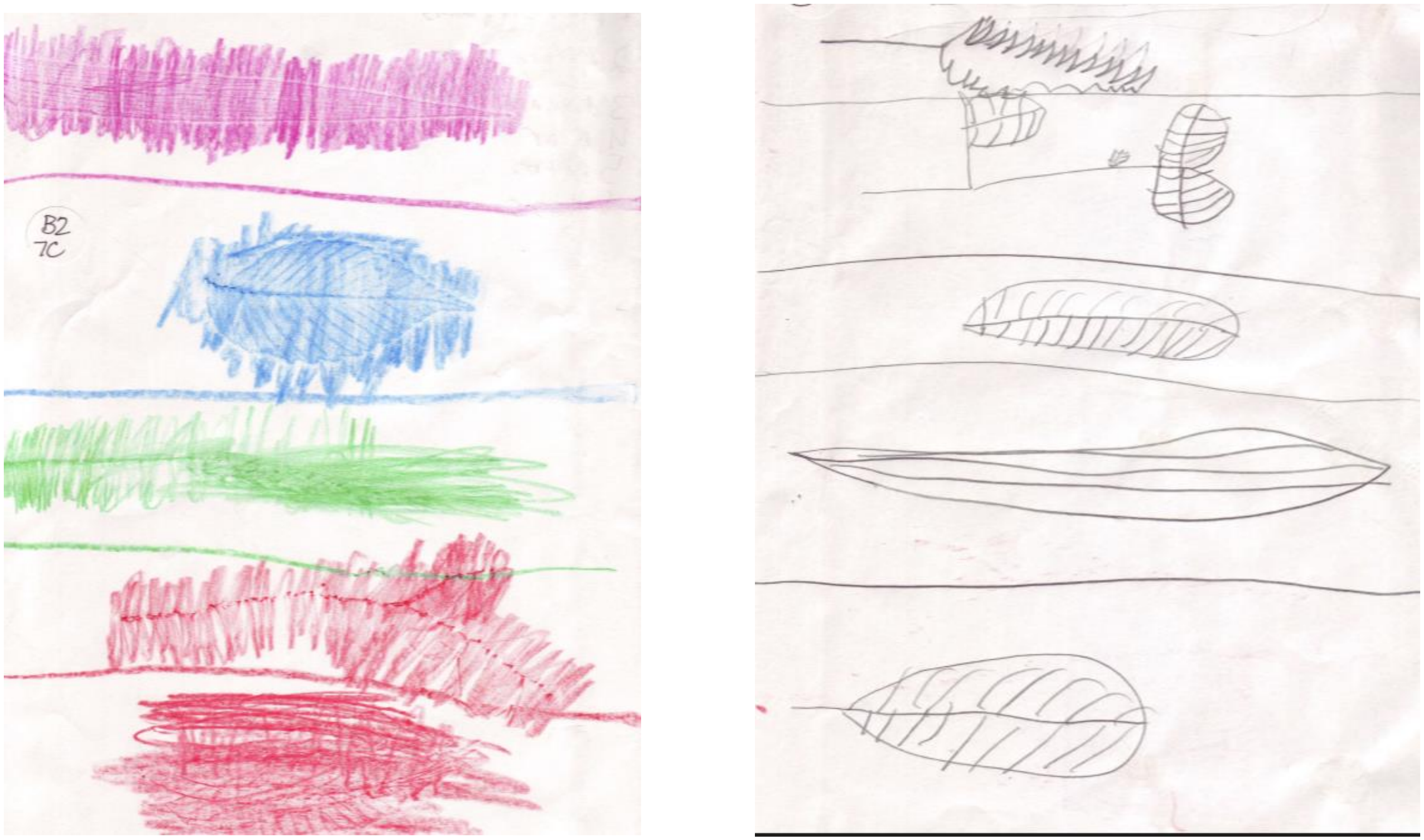


Figure 32: List of leaf rubbings and leaf diagrams (child nine)

The final example of how lists were used by the students is found in Figure 33. This particular example showed how a student created a list within a chart. As he/she collected data during the leaf investigation, the data for each leaf sample was recorded in a separate column. This was illustrative of the student's understanding that data must be organized. The lines separating each data point were futher indication of this understanding. Because the lines in each column section off varying sections, this example can be seen as a list rather than just a data table. It does appear that the student attempted to follow a similar order of observations for each sample listed, although some of the data appears to be incomplete. The overall effect of the organizational pattern chosen by this student, although unconventional, shoed a developing understanding that data must be organized and sequential. As a result, this provided another example of how the students were learning to participate in the larger Discourse of science during scientific inquiry. Their mastery of the skills and processes needed to communicated and represent their scientific understandings were still limited, but their approximations were beginning to represent those utilized by the larger scientific community.

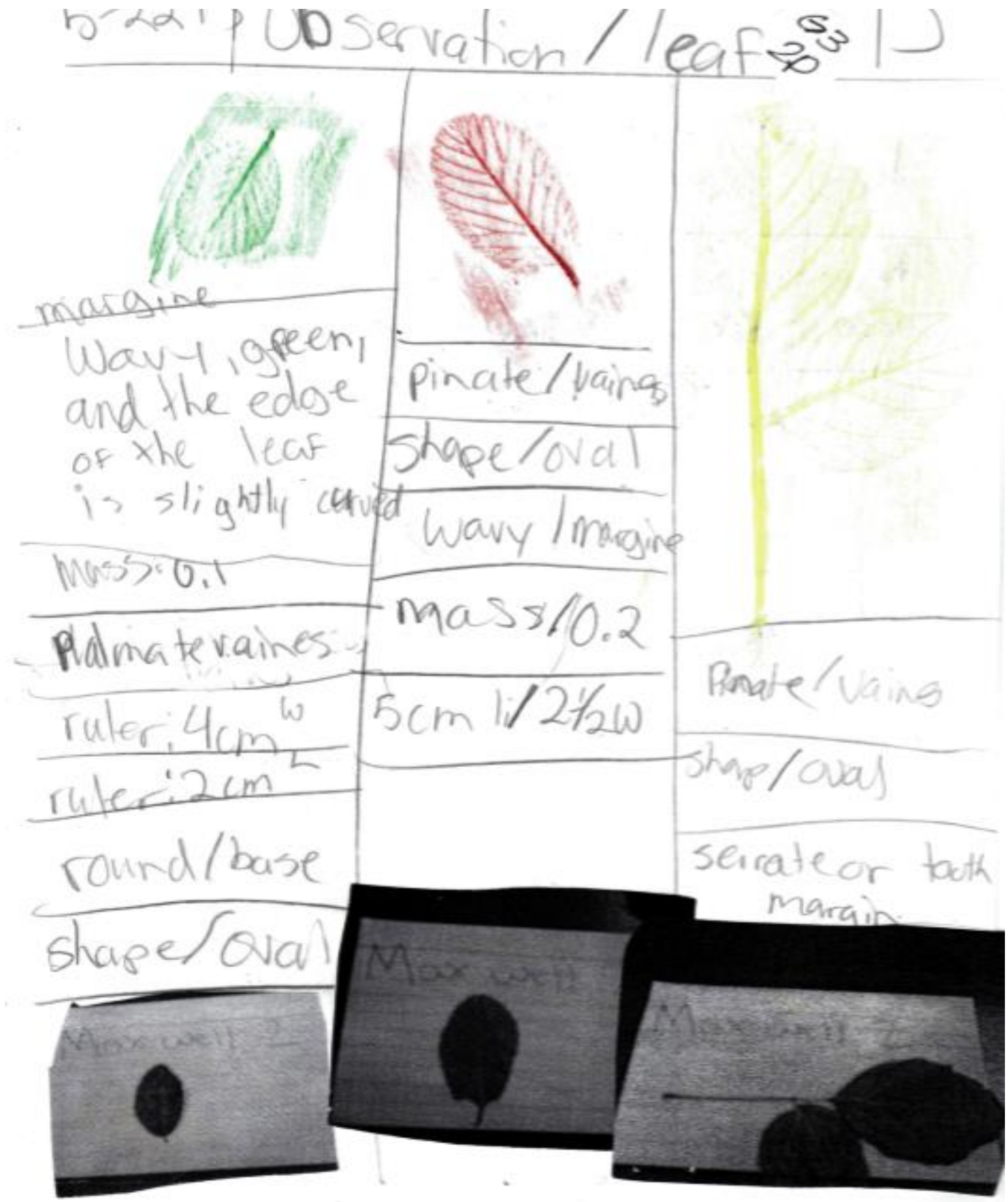


Figure 33: Combination of a list and a chart used to record data for the leaf investigation (child 14)

In looking specifically at how these lists were designed, it was important to note the wide variety of methods were used by the students to create lists. Drawing from a variety of semiotic resources, the lists provided in the previous examples for this section have shown that the students understand that lists can use hyphens, lines, or numbers to signify the various parts of the list. Figure 34 showed how bullets were also used to distinguish between the various parts of the list. Understanding these various forms for creating a list was representative of the students' developing understanding of the literacies of science. In order to participate in the Discourse of science, students must know how to represent and communicate their understanding of scientific concepts using the forms that are standard within the larger scientific community. This diversity of usage of lists showed that the students know a mulitple of acceptable ways to form lists. The examples provided previously also demonstrated that the students know how and when a list is appropriate.

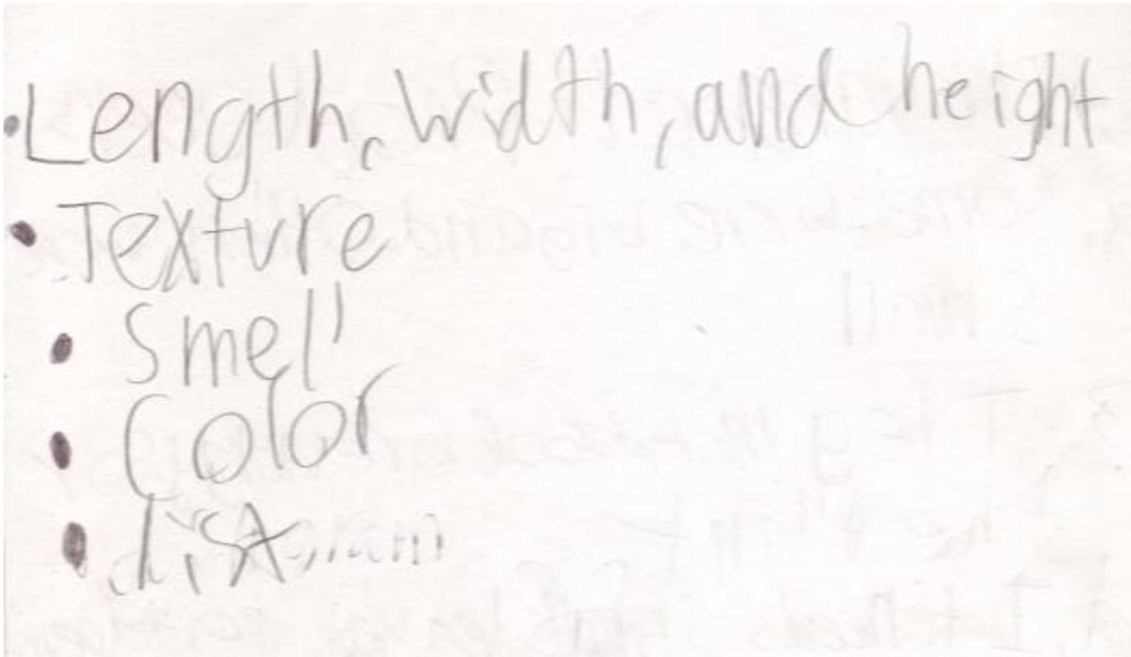


Figure 34: Bulleted list of an investigative plan (child five)

Diagrams

The second organizational tool used by the students to demonstrate their ability to think and act like scientists was to represent a scientific concept using a diagram. The diagrams created by the students and exhibited in Figures 35 and 36 show two different ways of depicting scientific information using diagrams. Figure 35 is an example of Child Two's understanding of how seeds travel. This picture illustrated how blowing wind can transport seeds to new locations so that they can survive. As part of the seed investigation, the students were allowed to observe or measure any characteristics that they choose, but one of their characteristics had to identify the way they thought the seed might travel. Child Two, showed one example of how these seeds travel.

A second example modeling how seeds travel was provided by Child Six in Figure 36. In this example, the student choose to use three separate, but connected diagrams to represent three different ways that seeds can travel: they can be blown by the wind, they can be carried by an insect or another animal, or they can be transported by water. These illustrative examples provided by the student demonstrated not only scientific knowledge about how seeds are transported, but they also showed the students' understanding of their ability to use diagrams to communicate this knowledge in a meaningful way. This is an essential skill that students must develop to participate in the larger Discourse of science.

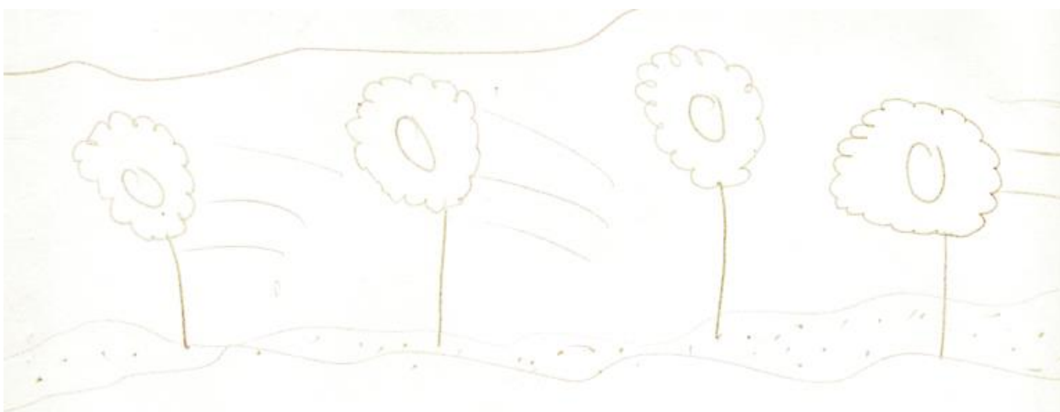


Figure 35: Diagram of sunflower seeds being blown to a new location by the wind (child two)

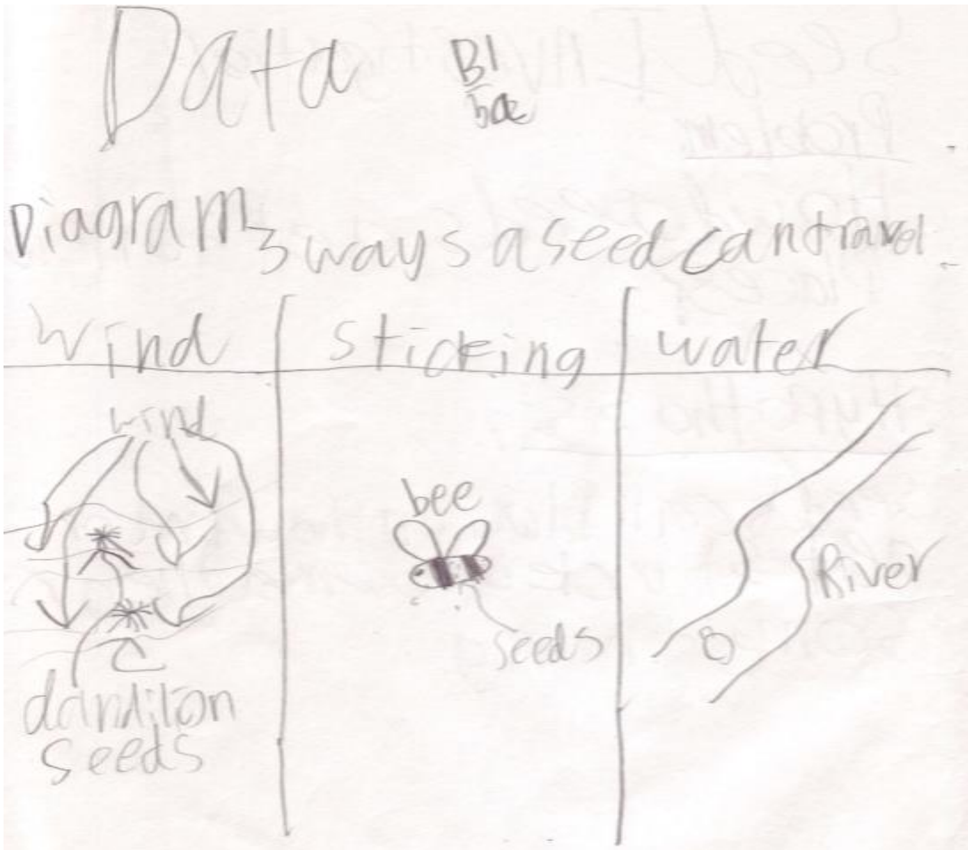


Figure 36: Diagram of the ways seeds can travel (child 6)

Another example of how the students were using diagrams to communicate scientific understanding comes from Child Four's logbook. In this illustration (seen in Figure 37), the student used what Moline (1995) refers to as a picture glossary. He/she has drawn a picture of a rose and has used words to label the significant parts of his/her drawing with the correct scientific terms for each structure. This in effect created a special type of scientific diagram known as a picture glossary. This type of diagram is a genre often used in textual representations in science and as such is representative of how the students are being apprenticed into the literary practices of the scientific Discourse.

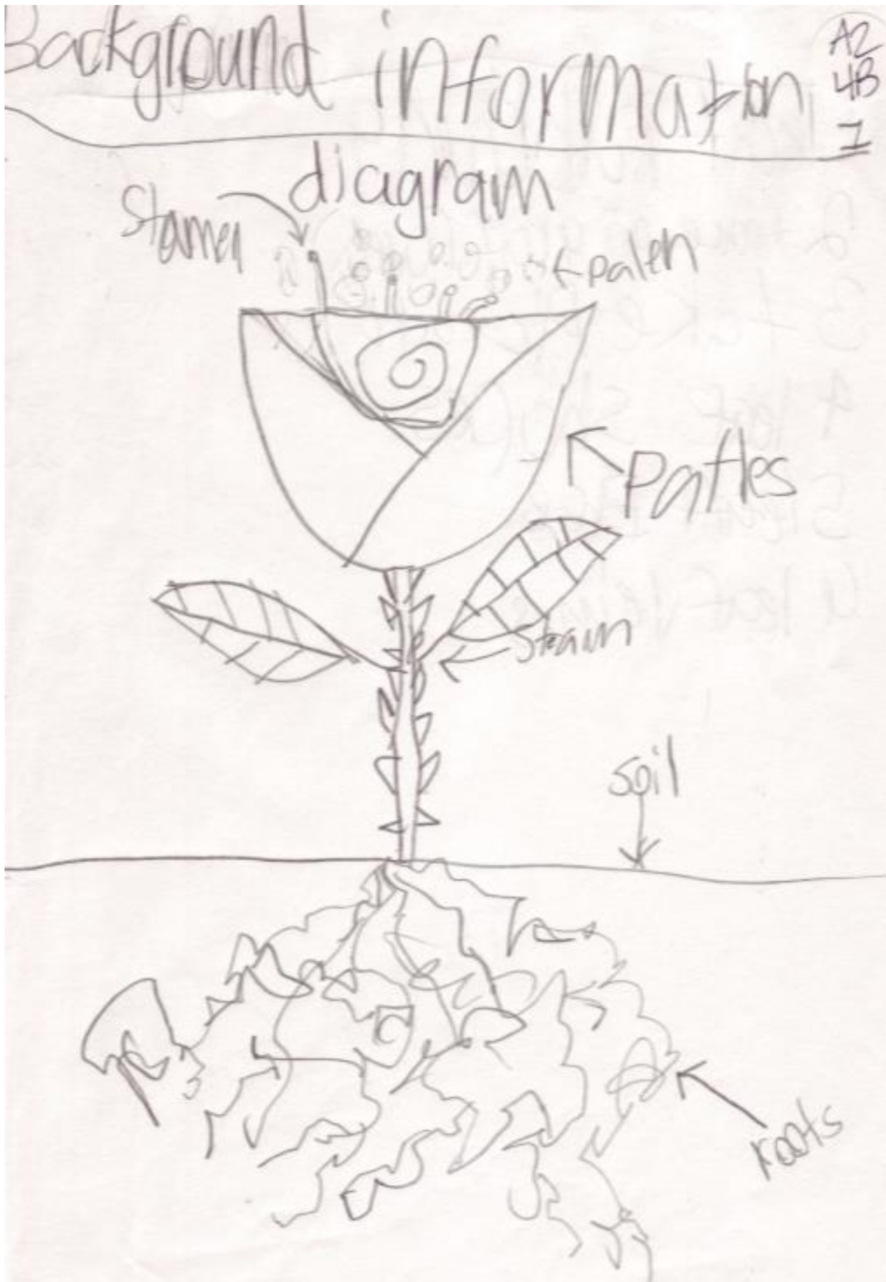


Figure 37: Picture glossary of what the student knew about plants before beginning the leaf investigation (child four)

T-charts

A third organizational tool that was utilized in many of the students' multimodal representations was a t-chart. T-charts are often used to make comparisons or to show a relationship between the two columns. In the data collected for this investigation, three main ways of using a t-chart existed and were illustrated in the examples that follow. The first way a t-chart was used is shown in the example from Child One shown in Figure 38. In this particular case, the student used the t-chart to compare what he/she knew about a plants' needs. This organizational structure was very effective at drawing the contrast between what the plant needs and doesn't need. It showed a strong understanding of the purpose of t-charts and how they can be used to communicate scientific understandings.

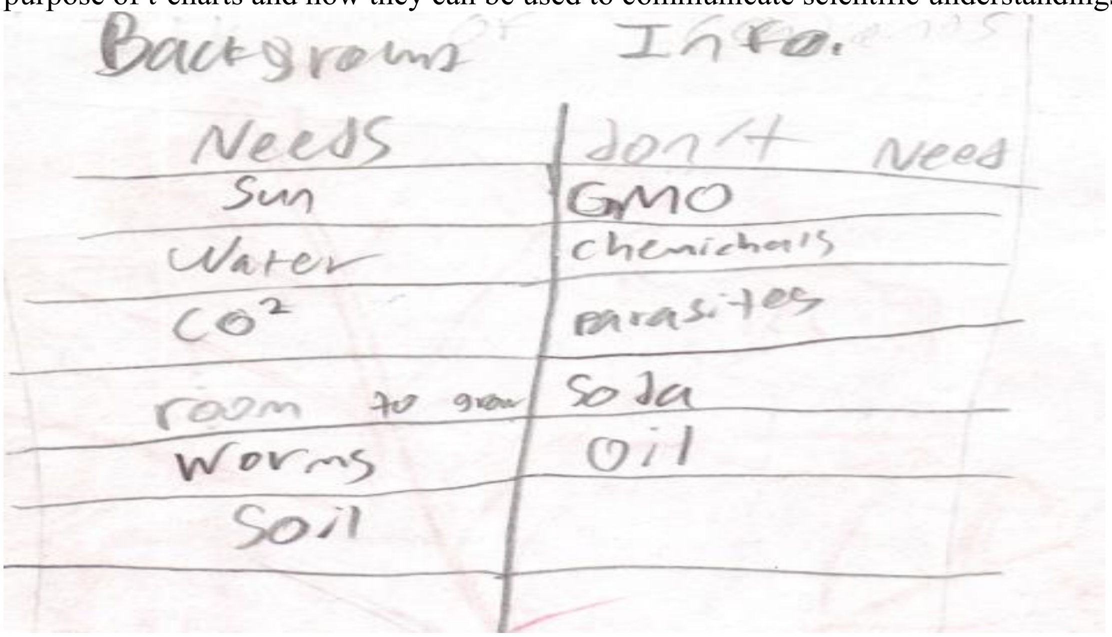


Figure 38: T-chart showing background information on plants (child one)

T-charts were also used by the students to compare what they knew to what their classmates knew as is the case in the example from Child 13 shown in Figure 39. Again, the t-chart shown in this example proves to be an effective organizational tool to draw this strong comparison. Both Child One and Child 13 exhibited their understanding not only of the t-chart as an organizational tool, but as a communicative tool to draw attention to its ability to compare and contrast varying points of view. This is a skill crucial to communicating scientific understandings.

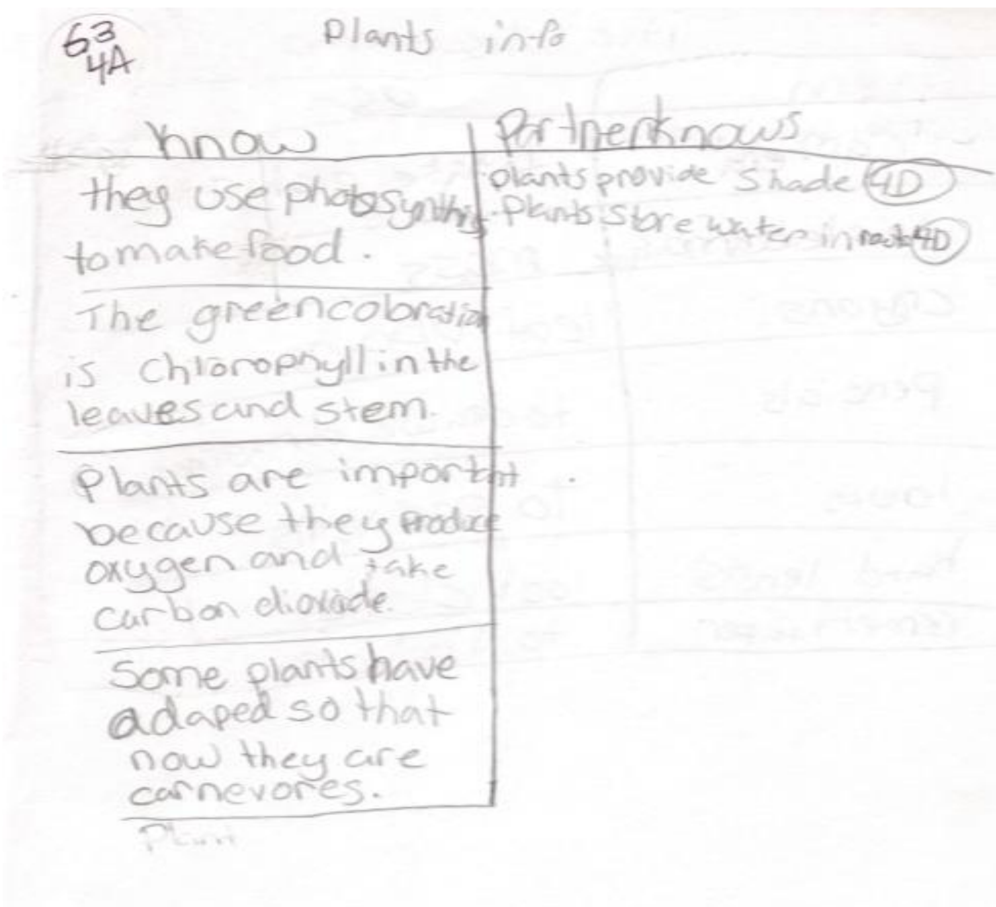


Figure 39: T-chart showing background information on plants (child 13)

An alternative, but just as effective, way of using the t-chart was modeled in Figure 40. In this particular example, Child 13 had created a second t-chart. Instead of making a comparison between him/herself and his/her partner, Child 13 had created this second t-chart to create a plan for his/her leaf investigation. As such, he/she had listed the tools that he/she would be using to make observations and had indicated how each tool would be used. This effectively and clearly communicated that the student understood his/her role as a scientist and the tools he/she would need to conduct his/her investigation which is indicative of his/her larger understanding of the literacies of science and how to use those literacies to communicate to the larger community of scientists.

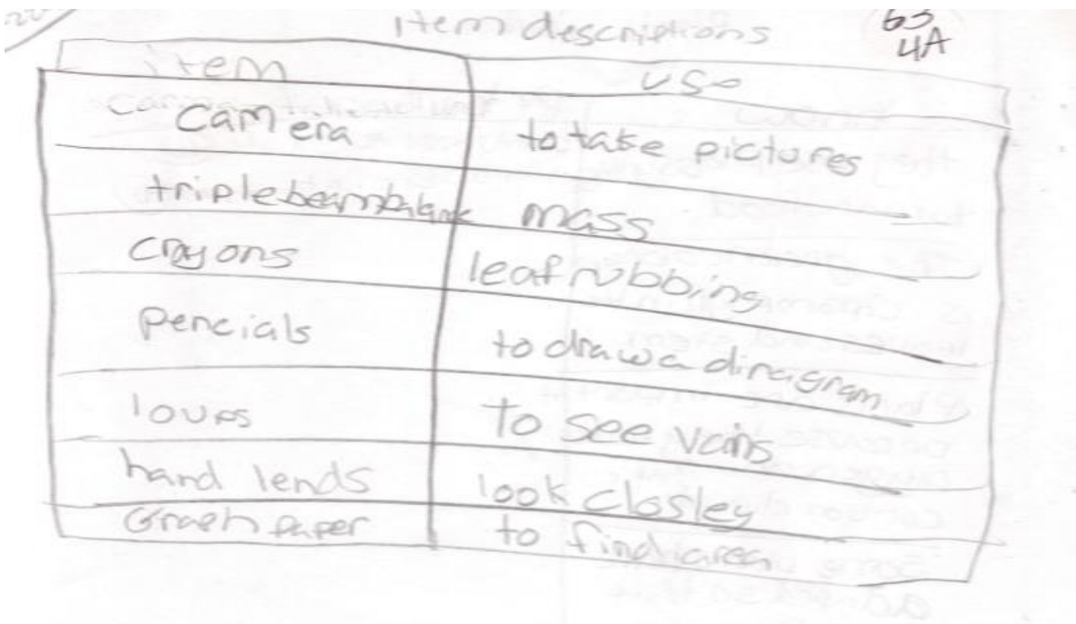
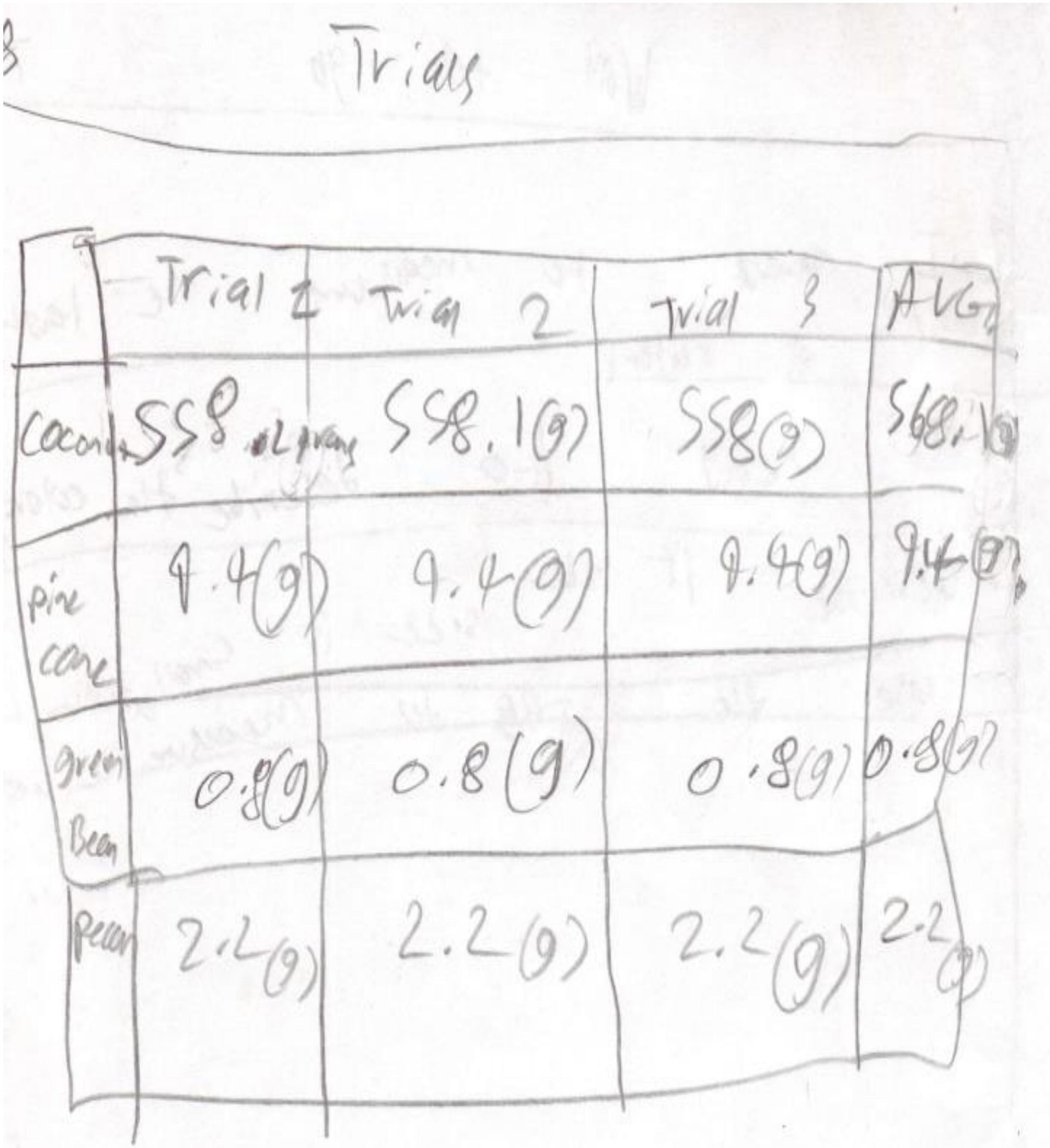


Figure 40: T-chart showing the scientific tools and their uses chosen for the leaf investigation (child 13)

Charts and Tables

One of the final organizational tools used by the students to represent their scientific understanding and participation in the Discourse of science was exemplified in the variety of charts and tables created by the students to organize their data. These tables have been specifically adapted by the students to best represent their data and to communicate their scientific findings to a larger scientific community by using forms appropriate and acceptable to the larger Discourse of the discipline of science. Some tables, such as the one found in Figure 41, have been created for the purpose of repeating multiple trials and calculating the mean of the data. Other data tables, like those found in Figures 42 and 43, were more descriptive in nature and had been created to accommodate both the qualitative and quantitative observations of the group's investigation. The variation of these designs showed that the students understood that tables and charts were merely organizational features that help make the data easier to understand. This understanding is a key indicator that these students were/are developing their ability to participate in the Discourse of science and that they were/are developing the literacies of science needed to do just that.


Trials

	Trial 1	Trial 2	Trial 3	AVG
coconut	558 .2 grams	558.1(g)	558(g)	568.1(g)
pine cone	9.4(g)	9.4(g)	9.4(g)	9.4(g)
green Bean	0.8(g)	0.8(g)	0.8(g)	0.8(g)
pecan	2.2(g)	2.2(g)	2.2(g)	2.2(g)

Figure 41: Data table for seed investigation with repeated trials (child one)

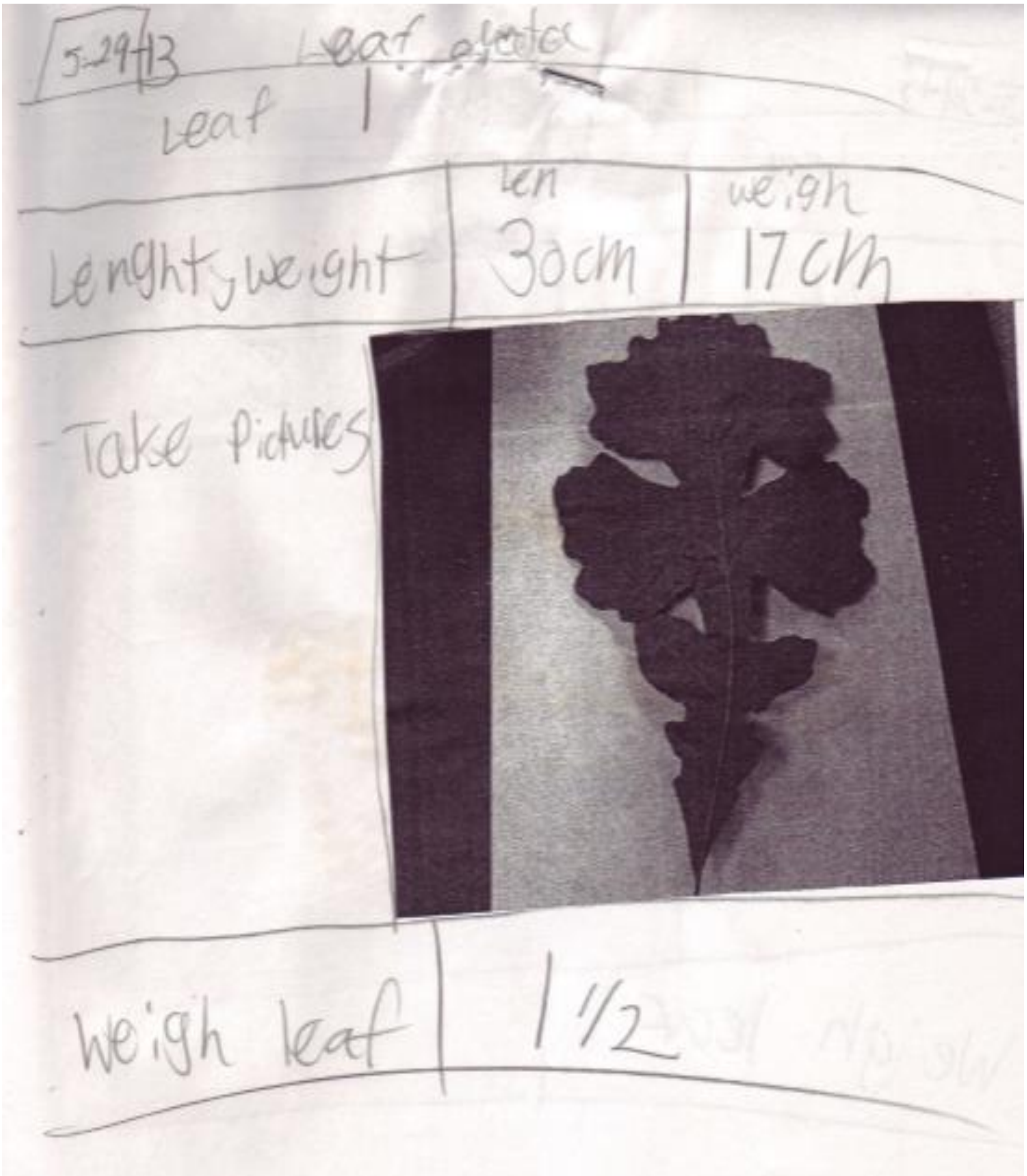


Figure 42: Chart to record leaf investigation data (child five)

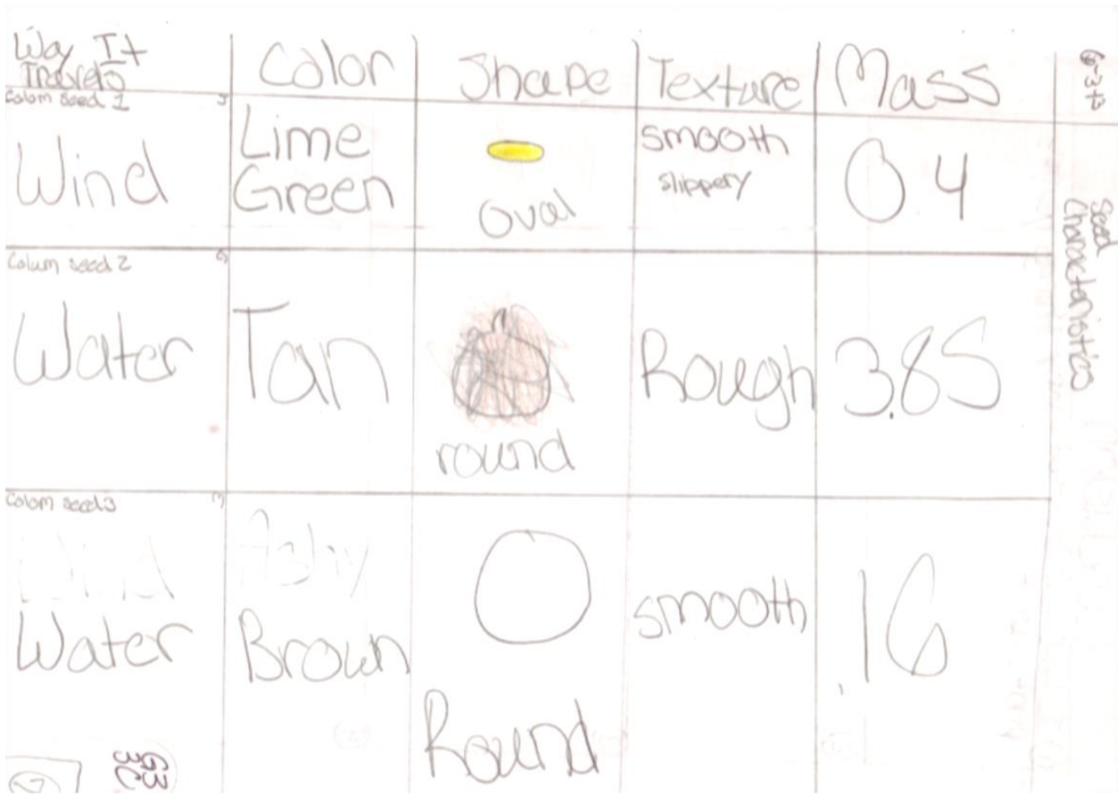


Figure 43: Data table for seed investigation (child 12)

Overall, the third theme that has emerged from the data illustrated that the students were developing their ability to communicate and represent scientific messages using forms and modes that were appropriate for communicating meaning to the larger Discourse of science. They possessed a broad understanding of the various organizational tools commonly used in science to communicate meaning and they have used that understanding to effectively communicate their meaning using lists, diagrams, t-charts, and other types of charts and data tables.

Theme Four: Influence of Previous Instruction and Experience

As part of the regular curriculum for the science program where this study was conducted, one of our main goals as educators is to apprentice the students into the Discourse of science by engaging them in practices that help them to think, speak and act like members of the scientific community (Gee, 1990). During their time in the science lab, the students are expected to learn how to work with a team and to develop their ability to use scientific tools to collect both qualitative and quantitative data. They record their data and communicate their scientific understandings from the inquiry process using the communicative tools and resources available to them in the science lab. These past experiences are part of the students' repertoires, and as such influence how the students choose to make and represent meaning. Each of the themes previously discussed have been influenced profoundly by the students' prior experience and instruction. This influence was evident in the data collected for this investigation and will be the topic of discussion for this fourth theme.

The collaborative lab groups that the students work in during their inquiry investigations provided the first evidence of how this prior experience and instruction has shaped the students' participation in the Discourse of science and has helped them to develop their literacies of science. The expectation for the science lab is that lab teams/partners are expected to work with one another in a fair and collaborative way during all science investigations. Because they are given the opportunity to practice working together on a regular basis during scientific inquiry, they do so naturally even when not explicitly directed to do so because this is part of how they have been trained to act and behave as scientists. Direct observation of the students during this investigation showed that all of the sixteen students participating in this investigation choose to work collaboratively with their lab partners during their investigation of leaves and seeds. This was supported by the transcript from the digitally-recorded interview with Child Six. During this recording process, Child Six specifically stated that the development of the group's plan, procedure, and data organization and collection were all decisions made by the entire team. This reliance on the group to make decisions was an indicator of this collaborative effort. Further collaboration was also noted when Child Three was describing his/her Multimodal representation. As described previously, Child Three is an English language learner. As Child Three was presenting his/her logbook he/she was unable to say a few of the words he/she wanted to use to describe her book in English. Without hesitation, he/she turned towards his/her lab partners and asked them how to translate the words he/she needed to communicate his/her understanding from Spanish to

English. Child Three's teammates provided the linguistic support that was needed, while Child Three in turn provided leadership to his/her group by guiding the design decisions for how they would represent the data in their logbooks. In the lab setting, this type of collaborative effort supports the large English language learner population in our school district and helps build an affirming and supportive learning community. The learning community established in the science lab is essential in teaching the students how to participate in the larger Discourse of science. As the students worked with their teams to make decisions during the inquiry process, many of the decisions they made were guided by their previous instruction and experience.

Experience and instruction also influenced the type of observations the students made during the inquiry process. As the second theme discussed in detail, much of the data collected by the students were both qualitative and quantitative in nature. During their normal lab times, the students have been taught how to use a wide variety of scientific tools to make both types of observations and how to do so accurately. Although these skills were/are still developing, many of the tools and the ways they were used were made evident in the multimodal representations they created to record their data. Such representations illustrated that previous instruction and experience were essential in helping students learn how to use the literacies of science in order to more fully participate in the larger Discourse.

A final example of how previous instruction and experience have guided the way students participate in the larger scientific Discourse was seen in theme three. Many of the students in this study created some type of graphic organizer to organize their data during the inquiry process. Many of the choices they made were modeled on the ways that we have used lists, diagrams, t-charts, and data tables during previous labs. A common model used in the science lab was represented by Child One. Child One set up a data table with room to conduct repeated trials, or measurements, of each leaf's mass and left a column at the end of the data table to find the average of his/her three trials (see Figure 44). The student also choose descriptive terms to identify each sample being observed even though no designation was made for the student. This example showed that the student was drawing on his/her previous experiences in the science lab, but also that the student was cognizant that scientists often use repeated trials. He/she was using an acceptable form of data collection accepted by the larger Discourse of science.

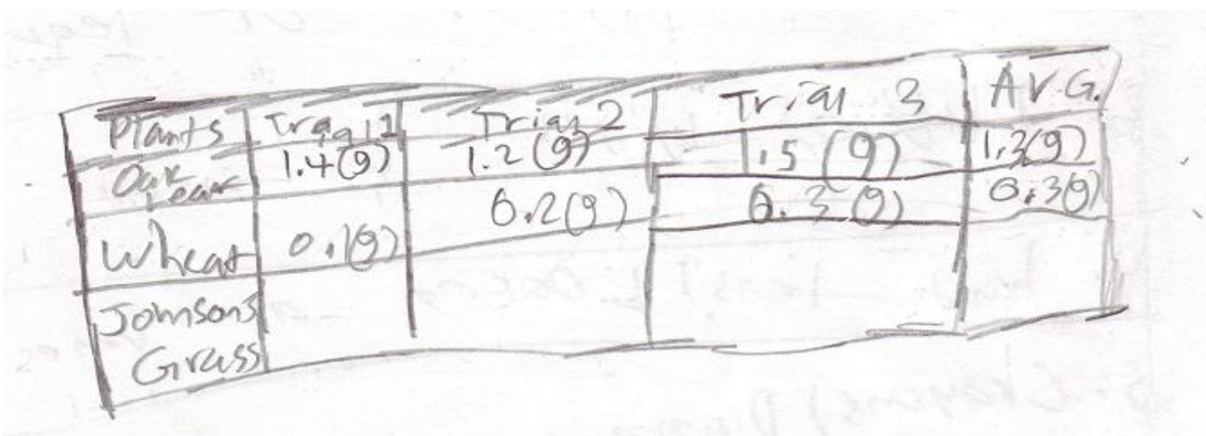


Figure 44: Data table (child one)

Child One, specifically referred to how previous instruction influenced the creation of his/her data table in his/her transcript. In the excerpt from the transcript for

Child One that follows, he/she stated that his/her group decided to use a data table to record their data because it was what they have been previously instructed to do.

> T: And, why did you choose to use a data table for this one?
>
> S: It's because like, it's very more organizing and just people kept on…they were always like "Just use a data table, use a data table." So, I just learned by doing all that.

Child 11 provides another interesting example of the previous instruction on the importance of repeated trails and on designating samples. In the first example from Child 11 (see Figure 45), the child identified each sample as a repeated trial because he/she was repeating the same test with three different samples. This was an unconventional use, but shows an understanding that scientists often repeat their investigation more than one time.

A second example from Child 11 (see Figure 46), comes from his/her second investigation with seed samples. This second data table showed that the student has decided to use numbered designations for each sample during this investigation rather than calling each sample a trial. This decision was a move towards a more conventional and socially accepted form of representation of the data.

Figure 45: Data table one from leaf investigation (Child 11)

title	coconut seed Seed 1	pine cone seed Seed 2	Avocado Seed 3
Mass	504.0g	17.5g	25.2g
Photo			
Color	Peach	brown	brown
Shape	sphere	Oval	Sphere
How it travels			

Figure 46: Data table two from seed investigation (child 11)

During this investigation on plants and seeds, the students participation in the Discourse of science and their development of their literacies of science had been influenced by their previous experience working as collaborative teams, by their previous instruction on how to use scientific tools to collect an assortment of qualitative and quantitative data, and by previous instruction that had shown them how to use graphic organizers to record their data and to communicate their scientific understanding.

Theme Five: Representational Development over Time

This final theme was one of the most significant themes for this study because it discussed how the students' representations of scientific concepts developed over even a short amount of time. Although this pattern was not directly found across all of the coding categories, its effect and significance did extend across each category. According to the literature reviewed for this study, one of the key indicators of scientific literacy is the students' ability to develop representational competency. Representational competency, as defined by diSessa (2004), includes the ability to construct, explain, evaluate, and critique the quality of various multimodal representations. Evidence of how the students' representations are changing even over a short period of time showed how they were developing this representational competency and were therefore a critical piece of these findings. This last theme discusses the examples of representational competency found in the data collected for this investigation.

To illustrate how the students' representations changed even during the course of this inquiry investigation, I have selected examples from the data that showed how the students attempted to rethink their representations of data within a given investigation, or how they improved their representations as they progressed from their first investigation to their second. I believe that this improved representation was indicative of a developing competency as defined above. The students themselves, were critiquing their own products and adjusting their representations in order to make improvements that they deemed were necessary in order to communicate their message more clearly.

The first examples reflecting the students' developing competency were best illustrated by samples from the logbooks of Child Five and Child Ten as seen in Figures 48 and 49. Figure 48, shows the first attempt by Child Five to design a data table for his/her leaf investigation. When Child Five's group realized that the spaces they had designated for each data source was not large enough for the data they would be collecting, they restructured their data tables to better accommodate their data. Both the original and the restructured data tables are provided. In order to accommodate the large space required to do a leaf rubbing and to find the area of the leaf on graph paper, Child Five's group decided to complete these two observations on separate pieces of paper and stapled them on top of the data table. This same procedure was followed for each leaf they investigated. Their restructuring of the data showed that they had reflected on the data they needed to collect and the best way to organize that particular set of data. Their second attempt provided a much more clear representation of the data and illustrated their growing competency.

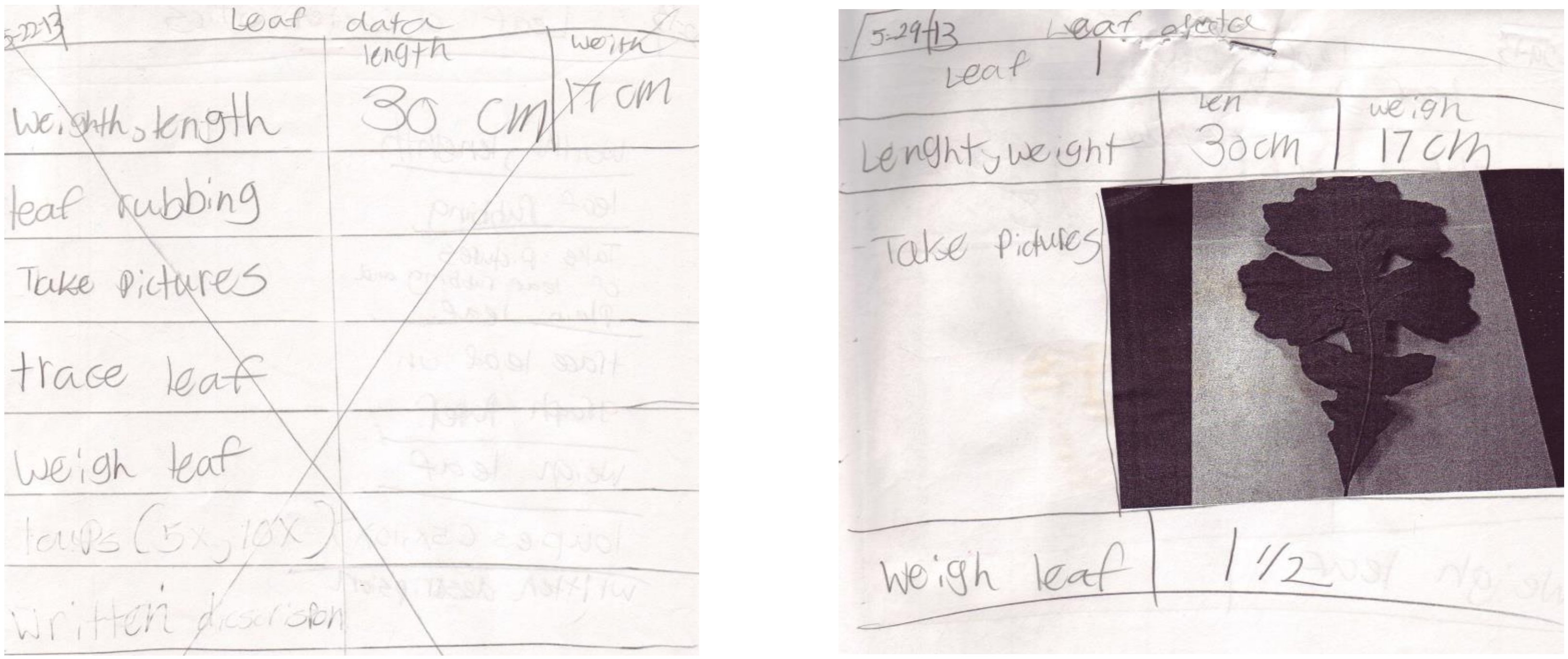


Figure 47: Example of how a data table was restructured during the leaf investigation (child 5)

The example from Child Ten (see Figure 48), shows an example of how another student attempted to restructure his/her data for clarity as well. In this example, the student initially listed the types of observations he/she was going to make for each seed. The data for each seed was then included in a numbered list next to the list of types of observations. In this first organizational attempt, the students' data was very cramped and it is hard to distinguish which set of data is for which sample. In order to make his/her data more clear, the student decided to restructure his/her data. As a result of this process, the student chose to create an expanded list with each seed and its associated data listed separately from one another. Although, still not a conventional way of displaying data, the student was showing that he/she understood that data must be represented in a way that is clear and easy to understand. This developing understanding was reflective of his/her growing representational competency.

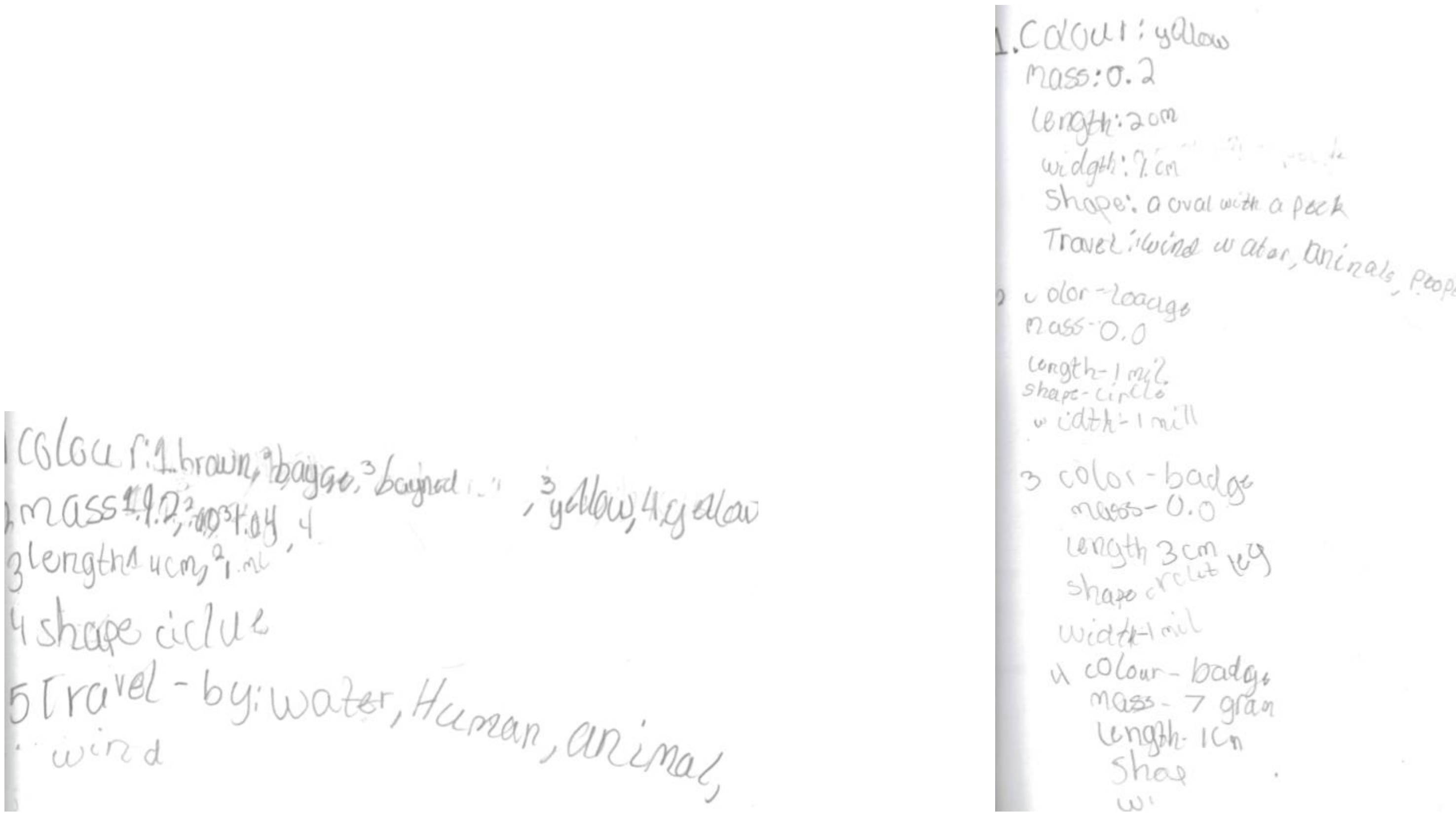


Figure 48: Example of restructuring a data table during the second investigation on seeds (child ten)

The next two examples of how the students were reflectiong on their design process were provided by Child Three and 14. In Figure 49, Child Three showed the development of data representation over the two investigations conducted as part of this inquiry process. In the first investigation, the student used hyphens and lines to provide separation between the data points. In the second investigation, the representation became much more consice and clear. The student chose to list the property being observed followed by a colon and then the data he/she has collected. The data provided in Figure 50 from Child 14 showed a similar reflective process, but on a different level. During the first investigation, Child 14 created separate columns for each leaf sample being studied and then listed the data for each leaf underneath the samples. Although organized, the information on this table is a bit unclear due to the inconsistant use of lines to separate the data points. Child 14 addresses this clarity issue by creating a more standardized data table for his/her second investigation on seeds. In this second data table, each type of data was made much more accessible for the consumer of this textual representation. His/her revisions were representative of his/her growing representational competency.

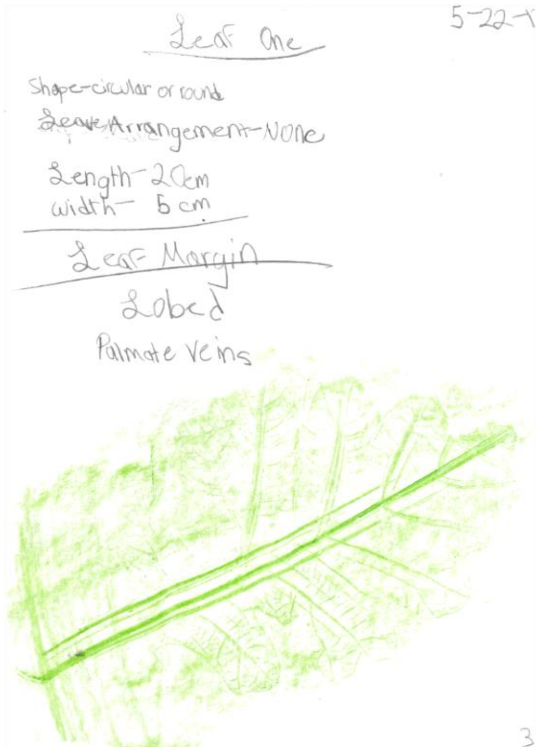


Figure 49: Example from data collected for both the leaf and seed investigations (child three)

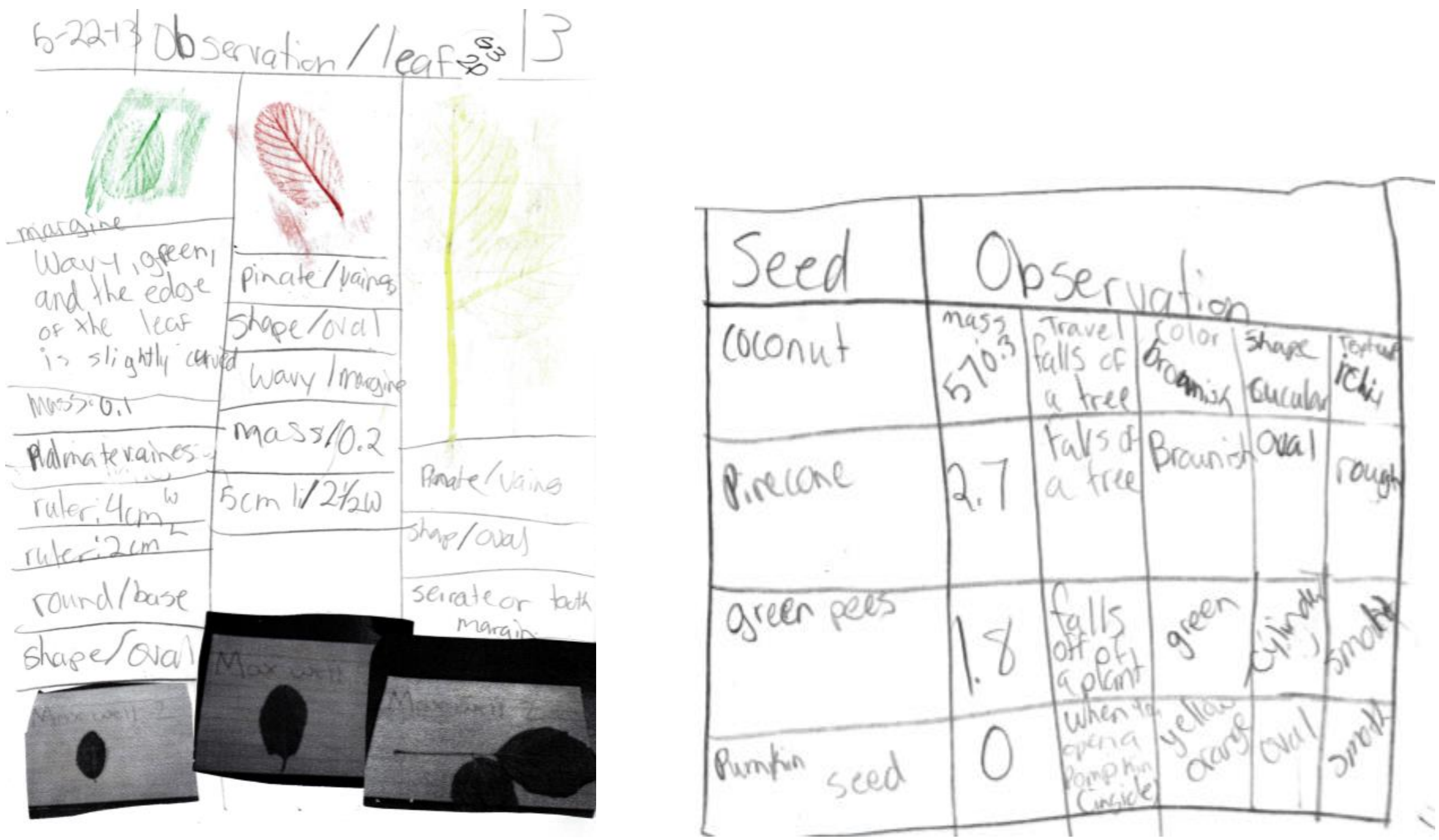


Figure 50: Data tables from both the leaf and seed investigations (child 14)

The final example of how these representations developed over time, was seen in the data tables provided by Child 11 in Figure 51. In this particular example, the student maintained his/her overall data table structure. The overall design chosen by this student was a standard form and indicative of the student's ability to participate in the Discourse of science. The change made by this student was a fine-tuning of this standardized form. In this example, Child 11 realized that his/her designation of the various leaf samples in the first investigation as trial one, two, three, and four, was incorrect. In a scientfic investigation, a trial repeats the exact same test the exact same way to ensure reliability of the data being collected. In this particular investigation, the child was repeating the same investigation, but was doing so with different samples in order to compare and contrast the samples. This was not a correct application of the word trial and was corrected by the student in the data table created for the second investigation. On the data table for the seed investigation, the student changed his/her designations from trial one, two, three, and four, to seed one, seed two, and seed three. This was a much more conventional and acceptable way within the Discourse of science to represent that different samples were being investigated.

Figure 51: Data tables from both the leaf and seed investigations (child 11)

Each of the examples provided in this section were indicative that the fourth grade students participating in this study were developing representational competency and were therefore becoming more adept at using the literacies of science. As such, these students were learning how to participate in the larger Discourse of science.

Summary

In this chapter, five themes that had emerged from the data have been discussed. We have seen that the children's ability to create and represent meaning and thereby participate in the Discourse of science has been greatly influenced by the support of the learning communities established in the science lab and was developed during the inquiry process. This inquiry process allowed the students to gather both qualitative and quantitative data using scientific tools. Scientific concepts were represented utilizing graphic organizers to various degrees and for multiple purposes. The interactions between the lab groups, the inquiry process itself, the representation of scientific concepts were all highly influenced by previous experiences of the students and the instruction they had been given. As the students developed their literacies of science they were able to represent their understandings with a greater degree of competency.

CHAPTER V

DISCUSSION

The purpose of this study was to utilize a Social Semiotic perspective of meaning-making to conduct a cross-case analysis of sixteen fourth grade students in order to describe the nature of the multimodal representations they created as part of the scientific inquiry process. These textual representations were indicative of the students' ability to effectively utilize the literacies of science to participate in the larger Discourse of science. The question guiding this study was:

> What is the nature of the multimodal textual representations created by fourth grade students during the scientific inquiry process?

This final chapter will provide an overview and discussion of my interpretation of these findings; connect these findings back to the current body of scholarly research reviewed in chapter two; discuss the implications of these findings; comment on the limitations of these results; provide personal reflections of each finding from my perspective as the researcher; and provide suggestions for future research and study in multimodal literacy and scientific inquiry.

Overview and Interpretation of the Findings

In Chapter 4, the five key themes emerging from the data and describing the nature of the multimodal representations created by students during scientific inquiry were discussed in detail. This section will summarize those key findings and provide an interpretation of their meaning.

Theme One: Support of the Scientific Learning Community

One of the first and most important, although unexpected, findings from this teacher action research project illustrated the way in which the students' ability to participate in scientific inquiry was scaffolded by the team they worked with during the inquiry investigation. Although working as a team was not a requirement for this investigation, it was allowed. All of the students, both those participating in this research study and those who were not, choose to work with their lab partners while they made observations of the leaves and seeds given to them during this inquiry investigation. This pattern of teamwork was one that had been established as part of the normal curriculum for the science lab throughout the course of the school year and was the way that the students naturally work while engaging in the inquiry process. Because this was a process that the students engaged in on a regular basis, and because they have had the opportunity to work with their same group of lab partners for the majority of the school year, each group had developed their own unique way of sharing responsibility, collaborating, decision-making, and solving problems. These qualities are the markers of a learning community and were evidenced in the data collected during this research study (Martin, 2007).

Because learning communities work together, emphasis during the inquiry process was placed on collaboration rather than competition. This emphasis was what allowed for the students to scaffold and support each other's learning. In this investigation in particular, the data showed that the students supported each other in three main ways. These three levels of support included: (a) conceptual support, (b) procedural support, and (c) linguistic support. While the students worked as teams, they were able to help each other by filling in each other's gaps in understanding so that the entire team could benefit and get instruction tailored to their specific individual needs. This type of support was readily received by all of the students because it was a very non-intimidating means of instruction. The lab partners provided this support naturally as part of their conversation during their science lab investigation, and it was often viewed by the students as conversation and group work, not as learning. It was a means of informal, but powerful instruction, provided as the students engaged in the inquiry process.

In my initial designing of this investigation, the support of the learning community was not a finding that I expected. My initial focus for this investigation was very teacher-centered and sought to find out how I could help the students become better at creating multimodal representations and how I could scaffold their meaning-making processes during scientific inquiry. Although I am a strong proponent of student-centered instruction, I failed to account for this valuable resource. My focus was too much on what I could do and not enough on how the community itself could support the learning process. I believe this was in part because supporting one another as a learning community and working in collaboration are such natural parts of our everyday interactions and as such are an integrated part of the normal curriculum in the science lab. Its impact had almost somehow become invisible to me. This research helped me to consider once again, the importance of the learning community/(ies) and allowed me to realize once again how crucial they are in helping to support the learning goals of the science classroom.

Theme Two: Making Qualitative Observations and Quantitative Measurements

The second theme that emerged from the data for this investigation, illustrated that students participated in the Discourse of science by making both qualitative and quantitative observations. These skills were ones directly taught as part of the normal curriculum and as such were expected. Their representation in the logbooks demonstrated that the students: (a) used scientific tools and field guides to make both qualitative observations and quantitative measurements; (b) had a growing understanding that scientists use the metric system to make quantitative measurements; and (c) possessed a developing realization that measurements must be repeated multiple times to increase the reliability of quantitative data.

This data illustrates that students recognized that scientific inquiry is a means of qualitatively or quantitatively descripting the world around them. Many of the students were able to select a wide range of scientific tools to collect both types of data. Evidence from the data collected for this research study, however, showed that the students were able to use the scientific tools and field guide resources with varying degrees of accuracy and skill. Although the skills and accuracy of a few were proficient, many of the students exhibited some errors in their usage of the tools, in their ability to accurately read the measurement tools, and/or in their consistent use of the metric system. Learning these "literacies of science" is part of learning how to think, act, and talk like a scientist (Lemke, 1990). They are skills that improve over time as these new scientists have opportunities to practice developing these skills.

This growing understanding of how to participate in the Discourse of science was also evidenced in the attempts of some of the students to use repeated trials in their investigations to ensure that their data was reliable. These efforts illustrated that the students recognize a need as a scientist to ensure that their data is correct and reliable, however, they are also indicative of the fact that some confusion about the inquiry process itself also exists. This type of descriptive investigation does not require the use of multiple trials. These students do not appear to have a clear understanding of the differences between the three types of inquiry that are part of their normal curriculum as required by the state of Texas. These three main types of investigations include: descriptive investigations, comparative investigations, and experimental investigations (Texas Education Agency, 2010).

Although, the fourth grade students have been engaged in all of these types of investigations, direct instruction about the distinctions between each type of investigation and the types of data or measures of reliability for each type of investigation have not been provided. This lack of instruction and the students' developing understanding of how to participate in the Discourse of science help explain the confusion evident in the students' representations. In this particular study, the students were asked to engage in a descriptive investigation. They were invited to make observations of several leaves and seeds and were able to collect both qualitative and/or quantitative data to describe their samples. This inquiry lesson, however, did not require the students to make any comparisons or "fair tests" which would have been indicative of a comparative or experimental investigation and required the use of repeated trials for reliability. The use of such measures, however, were indicative of the students' knowledge that scientific data must be correct and reliable. With experience and practice, the students will gain an even deeper understanding of the tools, resources, and standards of the discipline.

Theme Three: Use of Graphic Organizers

A third essential finding of this investigation was discovered by looking at the wide variety of graphic organizers used by the students during their inquiry process to meet their communicative and organizational needs. These graphic organizers included: lists, diagrams, t-charts, and charts and tables. Although the representational repertoires of the students are still developing, the data from this investigation showed that the students were effectively able to use each type or organizational tool multiple times and for a variety of purposes. This demonstrated that the students understood the investigative process, the type of data they were collecting, and how to represent that data in an appropriate manner. It also showed a clear understanding that the scientific community expects data and other scientific information to be represented in a clear, concise, and orderly way. The students showed that they knew how to choose organizational tools and semiotic resources that would help them to best meet their communication needs. This selection process was reflective of their developing understanding of the literacies of science and of their participation in the larger Discourse of science.

Theme Four: Influence of Previous Instruction and Experience

Another expected theme from the data was the role of the students' previous instruction and experiences in supporting their ability to participate in scientific Discourse, create meaning, and represent their conceptual understandings. This influence was seen throughout the research study, but the data explicitly illustrated its influence in the collaborative efforts of the lab groups, the quality and types of observations that were made, and how these observations were represented or recorded in the students' logbooks.

This was not a surprising finding. As a science educator, my job is to "apprentice" my students into the Discourse of science. As such, the normal curriculum provided to these students requires them to work collaboratively, to participate in scientific inquiry, and to learn the forms of representation used by scientists. Direct instruction or guidance has been given in these three main areas and as such is represented in the data collected for this investigation.

What was surprising about this finding, however, was the level of effectiveness of this prior instruction. Given the opportunity, the students were able to exhibit a level of self-direction as they worked with their lab partners during the inquiry process. The students were able to make decisions, problem-solve, plan, and conduct their investigations with little to no outside assistance. This ability showed me that as a group, we have been able to construct an effective learning community that benefits both the students and myself alike.

In looking over the types of observations chosen by my students, their choice of tools and the data collected using those tools, I was also able to learn about my students' skill and accuracy level. The students demonstrated that they had a strong grasp on how to use a variety of the scientific tools available to them and how each tool could be used in multiple ways to collect both qualitative and quantitative data during an investigation. As a science teacher, my goal was/is to train my students to be able to use a variety of tools to make quality, precise, and accurate qualitative and quantitative observations. Although many of the students were adept at using a variety of the tools, some of the data indicated some misconceptions about the type of units used in the science lab, or how to effectively use the tools so that the data is accurate and reliable. Misconceptions in the data also indicated that the students were unsure about how and when to use repeated trials as part of an investigation and/or which types of investigations require repeated trials.

The students were also very skilled at selecting appropriate graphic organizers to communicate their meaning. They were able to use a variety of lists for a wide range of purposes including: hyphenated, numbered, and bulleted lists. They were also able to use t-charts to compare and contrast information between groups. Charts and data tables were also created to record the data from their investigations. Much of the previous instruction provided to the students was focused on these various genres and their purposes and has been internalized by the students.

Theme Five: Representational Development over Time

The final finding was by far the most surprising of the findings for me personally. In reviewing the literature for this study, representational competency (diSessa, 2004) and representational fluency (Prain & Waldrip, 2006: Bezemer & Kress, 2010) were identified as key indicators of scientific literacy. As such, I expected that a longitudinal study of my students would provide evidentiary support for such a finding, but I was truly surprised to see how the inquiry process conducted during the course of two weeks could allow my students to reflect on the way they were representing meaning. During the inquiry process, my students engaged in two separate investigations—an investigation on leaves and an investigation on seeds. They were asked to choose five characteristics to observe or measure for three leaves and three seeds. This set-up was guided by the normal curriculum of the district. As their science teacher, I wanted to ensure that the students had an opportunity to observe the structures of both leaves and seeds that help them to survive in various environments. Because the students participated in two similar back-to-back investigations, I was able to see how my students revised their representations of the data from the first investigation to the second (and sometimes even within a singular investigation). In each example, the revisions made by the students helped the data to be more organized and provided their data with more clarity and structure. These revisions were indicative of their reflective process and of the role of inquiry in developing their representational competency. The inquiry process itself provides an authentic and meaningful place for these types of revisions to occur as the students reflect and improve their own scientific representations.

Context of the Findings

As a researcher, it is important for me to connect the findings summarized and interpreted in the previous section with current research. This next section will put the finding from this study in context by considering how the findings for this study either agreed, contradicted, or extended the current literature reviewed in chapter two of this study.

Theme One: Support of the Scientific Learning Community

Learning communities were and are a part of the normal curriculum in the science lab where this investigation was conducted. From their very first day in fourth grade, the students must learn how to collaborate with their lab partners as they engage in the process of scientific inquiry. This is part of how they are apprenticed into the Discourse of science (Gee, 1990).

Kozma (2003) illustrated how collaborative groups, similar to those established in the science lab were able to support this apprenticeship process. In the study conducted by Kozma, expert and novice chemistry scientists were paired together. This pairing allowed chemistry students who were new to the community of practice to work in collaboration with, and to copy the representational patterns of, the more experienced chemists. This apprenticeship provided the support and scaffolding necessary for these students to develop the representational competency required for them to participate in the Discourse of science.

The findings from this study found that the learning communities created in the science lab also allowed the students to provide this type of support for one another. Although all of the students in this investigation were fourth graders, their understanding of science and the inquiry process were still varied. Some students could be considered to be "experts" because of their advanced understanding, while others were still developing their knowledge of how to use the practices and literacies of sciences and could be considered "novices." This variance in ability allowed the students to informally assume the roles of an "expert" and/or "novice" scientist while engaging in the inquiry process as part of a learning community. The learning communities represented in this data showed that the students were able to provide three types of support for one another: conceptual support, procedural support, and linguistic support. It is important to note that these roles could easily switch even within the same inquiry session as one student might be the expert on how to use a particular tool while the other might be an expert on how to create a data table. This indicates, that apprenticeship can occur between solidly defined roles of expert and novice or between more flexible determinings of these roles. The important factor in either scenario is that those new to the community of practice, or those with less experience are often supported by the learning community as they develop these skills.

Repeated practice representing scientific understanding alongside more experienced scientists allows students to develop these skills. The process of scientific inquiry provides students with an opportunity to become more proficient at translating and negotiating meanings across various modes, thus developing their representational fluency (Prain & Waldrip, 2006; Bezemer & Kress, 2006). This development is often supported by efforts from teachers or others who are more advanced in these skills (see Lowe, 2000; Amettler & Pinto, 2002; Kozma, 2003; Leewalter, 2003; Chittleborough and Treagust, 2008; Coleman, Bradley, & Donovan, 2012). Again, this research was indicative that students are best able to develop their representational competency when supported by a learning community.

The work of Waldrip, Prain, and Carolan (2010) also supported the idea that students need multiple opportunities to practice constructing and justifying their representations. The data from this investigation demonstrated that this process is supported by working in a learning community. Learning occurs as students evaluate their representations, engage in talk about their representations, and make adjustments to represent or re-represent the concept. Tytler, Peterson, and Prain, (2006) observed this type of learning process during their investigation examining how students represented the process of evaporation. Similarly, in this investigation, the students worked together to restructure their representations so that their data would be more organized and clear. This could be seen either within a singular investigation or as they reflected on changes needed during subsequent investigations.

Theme Two: Making Qualitative Observations and Quantitative Measurements

As a Discourse, science has its own way of making, representing, and communicating meaning (Gee, 1990). The second theme presented in the findings for this research study illustrated how the students in this investigation participated in this unique meaning-making practice during the process of scientific inquiry. During this investigation, the students were given the opportunity to make multiple qualitative and quantitative observations of various leaves and seeds and to represent their findings in their science logbook. According to the literature, scientific inquiry is the process of "observing, describing, comparing, classifying, analyzing, discussing, hypothesizing, theorizing, questioning, challenging, arguing, designing experiments, following procedures, judging, evaluating, deciding, concluding, generalizing, reporting, writing, lecturing, and teaching in and through the language of science" (Lemke, 1990, p.1). Making qualitative observations and quantitative measurements is part of this overall process.

The fourth grade students were/are required to have multiple opportunities to engage in inquiry and to make both qualitative and quantitative measurements as part of their normal curriculum required by state law. Guidelines established by this law are found in the Texas Essential Knowledge and Skills, or TEKS (19 Tex. Admin. Code § 112.15 (b) (1-4), 2010). These guidelines specify student involvement in the inquiry process at least 50% of the time so that they can learn how to use scientific tools to make observations and metric measurements, record data, and create, represent, and analyze data and the natural world using models, graphs, tables, and charts. The fourth graders in this study have done just that.

The students participating in this investigation described the natural world qualitatively and quantitatively using multiple scientific tools and field guides. Representations of these observations were recorded in the students' logbooks. These representations showed that the observations and measurements made by the students varied in their accuracy and understanding of the standard way measurements were made by the larger scientific community. The students' correct and incorrect measurements are both instrumental in helping us to know what the students understand about engaging in the inquiry process. Their varying degree of accuracy, has the potential to illuminate where they are at in the conceptual development of how to accurately use the scientific tools and field guides to make observations. Tytler, Peterson, and Prain (2006) found that similar insight could be gained from the students they studied as well. During their study, they realized that students were able to represent what happens to the particles of water as it evaporates with varying levels of accuracy. As a result of their study, they found that there was a direct link between the conceptual understanding of the students and the representations the students created and that both representations (whether accurate or not) could reflect this conceptual understanding.

The guidelines that set the normal curriculum for science education in the state of Texas found in Texas Essential Knowledge and Skills, or TEKS, express that the students not only be able to use scientific tools to collect qualitative and quantitative data as part of scientific investigations, but that they should also be able to use repeated trials during their investigations to increase the reliability of their data (19 Tex. Admin. Code § 112.15 (b) (1-4), 2010). This is a concept that is directly taught to the fourth graders during the first six weeks of their normal curriculum for their unit on matter. During this time, the students are introduced to new scientific tools and shown how their data can become more reliable with repeated measurements. After this introductory unit, repeated trials during comparative or experimental investigations becomes an expectation in the lab.

The data from this teacher action research project showed that the instruction of repeated trials has been a part of the students' normal curriculum, even if it is a concept they have not yet mastered. The data from the students showed that they had a developing understanding that scientists must ensure that their data is organized and reliable. Yet, many of the students were not clear about how and when to use repeated trials. This was indicative that they do not understand the difference between descriptive, comparative, and experimental investigations, as defined by the state of Texas (Texas Education Agency, 2010). This also, was an example of how the partial understandings of the students are able to provide informative feedback that can guide future instruction (Tytler, Peterson, & Prian 2006).

Theme Three: Use of Graphic Organizers

The third theme drawn from the data showed that students were able to use graphic organizers for a variety of communicative and organizational purposes. According to the *Next Generation Science Standards* (NGSS Lead States, 2013), science education requires students to understand not only the processes and skills of science (exhibited by their ability to collect data during inquiry), but to be able to understand the semiotic practices, or “literacies of science” associated with the discipline as well (Lemke, 1990). Being able to competently represent and communicate these scientific ideas using graphic organizers and multiple semiotic resources is part of engaging in the semiotic practices of science and is in alignment with the theoretical framework guiding this study.

The theory of Social Semiotic espouses that various modes, or semiotic resources, are used to make-meaning in different contexts and are organized according to the needs of that particular occasion or as appropriate for the specific communicative purpose (Halliday, 1978: Kress and van Leeuwen, 1996, 2006, and Hodge and Kress, 1998). Students engage in the semiotic practices of science as they use multiple modes of communication to create their graphic organizers of their inquiry process.

For the students participating in this study, their logbooks (which were the site of display) for their representation, and the graphic organizers included in their logbooks, were a crucial part of how the students made and communicated meaning during the inquiry process. Other research, has supported this finding as well. Sandoval et. al (2000), conducted an investigation that looked at how multimodal representations support meaning-making, or the epistemological learning, of students in science. In their research, support is provided for the idea that multimodal representations can be used to scaffold the efforts of students to communicate, negotiate, and evaluate scientific meanings—all of which are part of the meaning-making process in science. Further research that supports the connection between representations and the development of scientific concepts is provided by researchers such as Brooks (2009) Prain & Tytler (2012), and Tytler, Peterson & Prain (2006). Brooks (2009) found that when students were allowed to use drawing to aid their visualization of science concepts that this supported their understanding of complex scientific ideas. Tytler, Peterson, and Prain (2006) also illustrated that the representation of scientific understanding created by a student (in this case of particles during the process of evaporation) is directly connected to their understanding of the scientific concept itself, whether the representation is accurate or not. Kozma (2003) and Sandoval et. al (2000) have also demonstrated the interconnection between conceptual development and the use of multimodal representations as thinking tools.

As a discipline, science often requires more than one semiotic mode, or meaning-making tool, to meet its communicative demands (Lemke, 1998). Students must understand these modes and each design element at their disposal in order to understand each mode's unique communicative or rhetorical purpose (Harrison, 2003). Research has shown that each mode has its own affordances and limitations (Bezemer & Kress, 2010; Kress 2004; Bearne & Wolstencroft, 2006). These affordances allow different modes to communicate different types of scientific understandings for different purposes (Prain & Waldrip, 2006). This study supports that finding. Students understood that t-charts are great tools for making comparisons, while data tables help provide organization and structure for data being collected during an investigation. They also knew how to use a combination of illustrations, words, and/or mathematical or numerical expressions to best represent their data. As the students selected from a wide range of organizational structures and semiotic modes to represent their data and inquiry process they demonstrated that they understood the various affordances and rhetorical purposes of each mode and were able to use them to communicate or represent their meaning.

In making these design choices, students were using multimodal textual representations to construct messages for particular social communities (Kress, 2004). This is a skill necessary for students. They must be able to competently represent and communicate their scientific ideas using multiple semiotic resources in order to participate in the Discourse of science (Gee, 1990).

Theme Four: Influence of Previous Instruction and Experience

The findings of theme four showed that much of how the students choose to participate in the inquiry process was directly influenced by the previous instruction provided to them and their past experience. This was true of how they collaborated as a learning community, of how they engaged in making their observations, and in the construction of their multimodal representations. Research reviewed as part of this investigation, however, does not confirm or support how or why this happens, but it does speak to the importance of previous instruction and the support that teachers provide in helping students learn how to participate in the Discourse of science.

The research reviewed as part of the literature review for this study, showed that teachers play an important part in helping to support the students' development of the "literacies of science" (Lemke, 1990). One way this is done, according to Gerstner and Bogner (2009), is by showing students how to interpret and create multimodal representations. Through direct instruction, teachers can draw their students' attention to and develop their student's understanding of the role visual images and other semiotic resources play in a text. Coleman, Bradley, and Donovan (2012) provided this type of explicit instruction by discussing the visual elements found in a text during read-aloud sessions with a class of second graders. This process allows teachers to 'expand the student's repertoires for interpretation (Serafini, 2011). Research has found that comprehension of visual images was supported when teachers directly teach or draw attention to the visual elements within a text (Lowe, 2000; Amettler & Pinto, 2002; Stylianidou, Ormerod, & Ogborn, 2002; Leewalter, 2003; Chittleborough and Treagust, 2008; Coleman, Bradley, & Donovan, 2012).

Research has also shown that in order for students to become competent designers of multimodal texts they must be taught about multimodality and elements of design

(Gerstner & Bearne, 2006). They must be taught: how various semiotic modes and mediums communicate meaning both independently and together; how to make design choices that best communicate the intended meaning to a given audience; and how to "read" the messages created by various semiotic resources. Part of their role as teachers is to instruct students how to choose the best modes, mediums, sites of displays, and frames to represent a particular scientific concept (Waldrip, Prain, & Carolan 2006: Tytler, Prain, & Peterson, 2007).

Although this study did not specifically focus on the influence of prior instruction, the representations created by the students did confirm that the experiences and instruction provided to the students previously influenced how they designed their multimodal representations of scientific concepts. Based on the former research and on the findings from this study, it can be postulated that more strategic instruction on the elements of multimodal design and practice creating multimodal representations during scientific inquiry could help the students develop their representational competency in science (diSess, 2004). Students must learn to replicate the ways in which real scientists represent meaning by practicing it themselves (Kress, 2004). During inquiry, students learn how to make appropriate design choices to best represent the scientific concept they have been studying (Kress, 2004). This process is developed by experience and exposure to multiple ways of meaning-making, including learning how to translate meaning across various representations in order to think and reason during the inquiry process (Kozma, 2003; Knain, 2006). Over time, and with practice, students learn to communicate scientific meanings more effectively (developing their representational competency) and become more proficient at translating and negotiating meanings across various modes, thus developing their representational fluency (Prain & Waldrip, 2006; Bezemer & Kress, 2010). This development is often supported by efforts from teachers or others who are more advanced in these skills (see Lowe, 2000; Amettler & Pinto, 2002; Stylianidou, Ormerod, & Ogborn, 2002: Kozma, 2003; Leewalter, 2003; Chittleborough and Treagust, 2008; Coleman, Bradley, & Donovan, 2012).

Yet, often teachers misunderstand the role they play or have misconceptions about how to support their students understanding. This was true in this research study as I underestimated the tremendous resource my students provided one another by supporting each other conceptually, procedurally, and linguistically during the inquiry process. Although research does not affirm this type of misconception it does show other ways that teachers have misunderstood the role they play.

The literature has shown that teachers occasionally assume that designing a multimodal representation is a way to incorporate student interest or learning style into a lesson to make it more interesting. Teachers often underestimate the complexity of the relationship between the various semiotic modes and the rhetorical purposes they play in a multimodal text (Barnford, 2003; Kong, 2006). The affordances of each semiotic mode equip it to communicate various scientific understandings for various purposes. Students must understand these modes and each design element at their disposal in order to understand each mode's unique communicative or rhetorical purpose (Prain & Waldrip, 2006). Tippett (2004), indicates that the design process includes: examining the choice of color and semiotic resources, understanding the rhetorical and communicative purposes of each semiotic resource, and selecting the message.

Moline (1995) suggested teaching practices to help students become designers of multimodal texts: discuss layout, typography, and signposts in multimodal informational texts the help students understand how each is used; provide varied opportunities for note-taking that allow students to make lists, create tables, and graphs, etc.; encourage students to "design" and not just "write" a text; use design elements such as boxes, arrows, and headings to organize and sort ideas; discuss alternative ways of representing a concept that can communicate a message more clearly.

Theme Five: Representational Development over Time

The final theme presented by the findings of this research study, indicated that scientific inquiry itself is a process that allows students to have an authentic context where they can practice and reflect on their representations of scientific meaning in order to develop their representational skills over time. This was specifically evidenced by looking at the way the students restructured their data either within a singular investigation or from one investigation to another to make their data more clear. The revisions made by the students showed that their abilities as designers improve with practice and over time. Such revisions are concurrent with the work of Waldrip, Prain, and Carolan (2010) who espoused that students need multiple opportunities to practice constructing and justifying their representations. These experiences revising representations are part of the learning process. Tytler, Peterson, and Prain (2006) discovered that learning occurs when students are able to evaluate their representations, engage in talk about their representations, and make adjustments to represent or re-represent concepts. In follow up work by Tytler, Prain and Peterson (2007), the researchers found that students need to be given the opportunity to think and process scientific information using multiple representational modes and to extend and enhance current representations through multimodal translation work. By engaging in subsequent investigations of leaves and seeds, the fourth grade students had the opportunity to do just this. The improved clarity and organization and shift towards more conventional modes of representation exhibited in the examples provided by the fourth graders in this study show that the students were extending and enhancing their representations. The inquiry process has also allowed the students to learn to replicate the way real scientists make meaning by practicing it themselves (Kress, 2004). Over time, the students will learn how to communicate scientific meanings more effectively, and as such, will be able to provide evidence of their developing representational competency. It is their ability to represent scientific concepts effectively that is a key signifier of their scientific literacy skills and their ability to participate in the Discourse of science.

Implications of the Findings

The purpose of this study was to provide a rich description of the nature of multimodal representations being created by fourth grade students as part of the inquiry process. This understanding was important because it will help teachers better equip students to both interpret and design multimodal texts that are able to effectively communicate scientific understandings. The findings from this study, illustrated five important observations about the nature of the multimodal representations created by the students. The following section will discuss the implications of the findings based on those five major themes.

Theme One: Support of the Scientific Learning Community

This study has shown that the representations created during the scientific inquiry process and the inquiry process itself were both directly supported by the learning communities established in the science lab. These groups were able to provide conceptual, procedural, and linguistic support that strengthened the overall learning of the group. As a result, this study illustrates the importance of developing a classroom or laboratory environment that supports the development of such learning collaborations. Teachers must provide opportunities for students to engage in scientific inquiry not only as independent investigators, but as part of collaborative group. The use of collaborative groups allow the students to support each other in the development of their scientific literacy skills while also allowing the students to build their skills of communication, collaboration, critical thinking, and creativity. These 4 C's are what have been identified by the Partnership for the 21st Century Literacy Skills (2014) as "super skills" for the 21st Century.

Theme Two: Making Qualitative Observations and Quantitative Measurements

This study has also shown the importance of helping students to understand the difference between descriptive, comparative, and experimental investigations. Many of the representations created by the students indicated that they knew how to use scientific tools to collect both qualitative and quantitative data, but had some uncertainty about how to best represent their findings in accurate and reliable ways. Directly teaching the differences in these investigations, the types of data appropriate for each, the tools and skills necessary to collect precise and accurate data for each type of investigation, and the appropriate means necessary to ensure that the data collected is reliable is essential.

Many inferences as to how to build my students' ability to use the scientific tools available in the science lab can also be gathered from the data form this investigation. Many of my students illustrated varying degrees of accuracy in using measurement tools. As a result, specific attention needs to be given to providing my students with instruction on how to use each tool in a way that allows them to obtain the most accurate measurement possible with the tool they are using and how that measurement should properly be recorded. Helping my students represent these measurements in a conventional manner equips them to more easily participate in the Discourse of science. Multiple opportunities to practice building these skills are essential to this ongoing development of the literacies of science (Lemke, 1990).

Theme Three: Use of Graphic Organizers

In order for students to learn how to effectively communicate and represent their understanding during the inquiry process, the data from this study has shown that students need to be provided with opportunities to learn about the genres/modes of representation commonly used within the discipline of science and given the opportunity to engage in experiences where they can create these types of representations for themselves. This replication of the work of “real” scientists is at the heart of the “apprenticeship” process identified by Kozma (2003) (see also Gee, 1990). Students must be taught the elements of multimodal design as part of their normal curriculum so that they can develop the literacy skills of the discipline. The data from this study also indicates that students must be given multiple opportunities to critique, analyze, and modify their representations in order to develop their representational skills.

Theme Four: Influence of Previous Instruction and Experience

The implications of theme four echo the implications from the first three themes provided in this study. The data from this investigation supports the ideas that students need to be allowed to work in collaborative groups, have both direct instruction about the practices required to engage in scientific inquiry and the forms of representation used within the discipline of science, and opportunities to apply that knowledge and reflect on their experiences. These opportunities allow the students to build their conceptual and representational repertoires, thus supporting their ability to think and act like others within the scientific community.

Theme Five: Representational Development over Time

This last theme, provides evidence that science teachers need to teach not only scientific concepts, but elements of design. As such they must work, cooperatively with their students to develop a meta-language to discuss and critique multimodal representations in order to equip their students with the skills necessary to become effective communicators/representors of scientific knowledge. Through this process, students can become familiar with the rhetorics inherent within each semiotic mode, and make intelligent design decisions about how to best represent their intended message to their audience. Such conversations help students to understand how scientists represent/communicate scientific meanings and help provide students with a model for replication. As with any skill, the students need time to practice developing their representational skills and must be allowed to revisit and reflect on their representations in order to critique their own work and find ways to more effectively represent their meaning. As indicated by this data, the teachers can allow this reflection to occur naturally with carefully selected learning opportunities.

Limitations of the Findings

Although the limitations of this study were discussed as part of the methodology section in chapter three, this section attempts to discuss the limitations of the findings in particular by looking at limitations of methodology, limitations of implementation, and limitations that I encountered as the researcher in order to increase the credibility for this study.

Methodological Limitations

This investigation from its onset, was designed as a teacher action research project in order to help me, as an educator, provide my students with better instruction. None of the other studies reviewed prior to the start of my research utilized teacher action research, and as such provided little support in the design of my methodology. I decided, however, to conduct a cross-case analysis of multiple cases in order to discover any patterns that I could about the nature of multimodal representations created by fourth grade students during scientific inquiry. In total, sixteen cases were selected from the entire fourth grade student population in my school district (which ranged between 180-190 students). These sixteen students were ones who had volunteered and who had returned a signed consent form to me prior to the start of the study. As such, the data collected for this investigation came from a very small sample of students and was a sample based on convenience. Although small, the sample itself is somewhat representative of the larger population in ability level, gender, ethnicity, and socio-economic background. A larger, or more homogeneous, sampling of students might yield different results.

Implementation Limitations

A few issues with the implementation of this study must also be disclosed. In setting up the inquiry lesson for my students, I wanted to leave the options for student choice as open as possible while still meeting the curriculum objectives outlined in the curriculum documents provided by our district. Because the students were currently learning about the adaptations of plants and animals, the inquiry investigation needed to support those learning goals. Observing the structures of leaves and seeds was an appropriate choice that met both goals. In the planning for the inquiry investigation, however, I included more tasks than the students could complete given the time remaining in the school year. Some modifications had to be made during the process of the inquiry investigation and some of the students were asked to move on to the seed investigation before completely finishing their observations of the leaves. Although, more evidence for each of the findings discussed in chapter four may have been made available if time had allowed these students to finish both sections, I do not believe it would have altered the findings themselves. The patterns of data found across the samples were consistent in demonstrating the patterns discussed in the findings section.

A second implementation limitation that must be discussed arose with the digital-recording process. Due to the active lab environment and trouble with the digital-recording equipment, the recordings for two of the students were lost. One of the students re-recorded his/her description of his/her logbook, but the second description was not as detailed as the initial recording. This loss of data was difficult, but because the logbooks for both of the students were still complete, they were included in the overall collection of data and I believe they contributed significant information that would have been lost if they would have been excluded from the data set. Although, the original digital-recordings would have provided insight from the child's perspective, again, I do not believe that it would have resulted in changing any of the findings.

A final limitation of the implementation of this study resulted from the choice to use a heterogeneous grouping. The group was diverse in ability, gender, ethnicity, and socio-economic background which is reflective of the larger population to a large extent. A homogeneous group or two distinct groups chosen for comparison purposes might provide different findings from the ones provided here. The choice to utilize a heterogeneous group, however, was made based on convenience and is helpful to me as their teacher because it is reflective of the larger school population.

Researcher Limitations

As a teacher-research, my own personal bias must also be discussed as a limitation to the findings. Even though I have tried to limit the extent that my own biases have affected the findings from this data, I must recognize that my position as the science lab teacher, my relationship with each of the students participating in the study, my own cultural and socio-economic positioning, my identity as a doctoral student, have all influenced the way that I have approached an analyzed the data for this investigation.

As a science lab teacher, I am placed in a position of authority and am part of and yet outside of the learning communities established by the students. Although, I am able to provide an insider perspective to some extent it is limited by my role as a teacher at our school. I also have a vested interest in what the students know and do not know as this in part is internalized as a personal reflection on my job as one of the students' science teachers and as the science coordinator for our building. It is my job to reflect on what our students know and to make decisions about how to move them forward. This helps me to have the analytical eye necessary to find the patterns in the data, but it has limited what I see to what I have previously deemed as important. To accommodate for this, I continuously tried to allow the data to speak for itself and to allow the students' voices found in their transcripts to guide my "seeing." As a result, I did stumble onto a few surprising findings that will change the way I shape future instruction.

Culturally and socio-economically, I come from a very different background from my students. Although, I work to be sensitive to these differences and try not to value my way of knowing and doing over other, equally valuable ways of knowing and doing, this at times is not possible due to curriculum standards, etc. Part of my role as a science teacher is to teach students to think and do things like other scientists, not because it's better, but because it is the expectation of the curriculum standards. In a sense, I am imparting to them another way of trying to see the world while trying to cognizantly value the way they already see it. Despite my greatest efforts, however, I know there are times when I unconsciously impose my values on the students. I have tried to control for this in this investigation by conducting a peer review and member checks.

As a doctoral student conducting an investigation myself, I have been able to draw many comparisons between the inquiry process my students were engaged in and my own work. As I have experienced my own partial understandings and experienced ahh hah moments, I have been able to identify uniquely with the process represented in the representations created by my students. From participating in the inquiry process myself, I have gained new insights into how to better teach the inquiry process to my students. As result, this will change my teaching practice in the future, but its effect on the findings for this study is minimal to none.

Researcher Reflections

The origin of this study arose out of my personal reflection as a practioner. I wanted to use this teacher action research project as a means of improving my students' ability to make-meaning during scientific inquiry and to represent these meanings more effectively. As this study has drawn to an end, I feel it is appropriate to once again spend a moment to personally reflect on each of these themes. Although some brief general reflections were considered in the previous section, this following section will specifically consider my personal reflections for each of the findings according to the major themes that developed from the data analysis.

Theme One: Support of the Scientific Learning Community

In the district where this investigation took place, learning communities are a natural part of the inquiry process and normal curriculum for the fourth grade students. This study helped me to realize how these learning communities naturally provide conceptual, procedural, and linguistic support for my students during the inquiry process. Thanks to the data analysis conducted for this investigation, I realized that I have underestimated the importance of these learning communities in scaffolding the learning of the students. My future instructional decisions will no longer ignore this valuable asset, but will try to utilize this resource to its fullest advantage without hurting its integrity. My underestimation and oversight in this instance, however, causes me to wonder what other resources or hindrances to learning I might have overlooked due to my familiarity with the study's setting. Such an awareness will help me to look at the learning environment I share with my students and the lessons I provide with renewed sight.

This particular theme, has also challenged me to question my assumptions about the way the learning communities in the science lab interact to provide the type of support evidenced in this study. As a result of this investigation, I have realized that I have made assumptions about the way my students share responsibility while working on an investigation. Although, I believe that the data from this investigation showed a collaborative effort amongst all of the groups, the data does not provide specific data about how these groups specifically interacted. In the past, I have tried to structure the roles of the groups with cooperative learning group roles, but have been unsuccessful at achieving this. The focus when using these set roles becomes on policing one another's roles rather than on the investigation itself. I have chosen a more organic approach to the roles in the learning communities intentionally to keep the focus on the inquiry process and not on the roles of the students. I intervene when I see someone being too bossy or dominate, when a group is having difficulty working or communicating, or when a group requests help. In drastic situations, I may move a child to another group, but this is done very rarely. Even though, there was evidence of learning communities being established and of them working in collaboration, as a teacher I would like to know more about how to help support the collaboration of these learning communities to ensure that the roles of the students are equitable and democratic.

Theme Two: Making Qualitative Observations and Quantitative Measurements

One of my main jobs as a science teacher is to help my students participate in the Discourse of science by learning how to describe the natural world around them by correctly and safely using a variety of scientific tools and resources to make qualitative and quantitative observations. My goal is to help them develop their ability to make these observations with more and more precision and accuracy. During this investigation, there was significant evidence supporting the students' development in these areas and even the misconceptions proved to be resourceful in providing insight into the students' understanding. In general, these gaps in the students' knowledge reflect gaps in instruction or lack of opportunities to practice. As an educator, I want to be sure to provide my students with both the instruction and opportunity to develop their literacies of science effectively so that they can more fully participate in scientific Discourse.

Theme Three: Use of Graphic Organizers

In looking at how my students used graphic organizers to communicate or represent meaning, I realized that they were developing their skills as designers of multimodal representations without any direct or intentional instruction from me. The students were able to carefully select and represent a wide variety of messages using a large sampling of forms to best communicate their meaning. Some of their attempts were very effective, while others were lacking, but both provided insight into how I as a teacher could better teach my students to represent their scientific understandings multimodaly. Where limitations in my students' understanding of how to represent their scientific knowledge existed it seemed to be reflective of the limited instruction that I or the other science teachers have provided.

With this insight, both the other science teachers and I can be more intentional about equipping our students to be designers of multimodal texts. We can provide direct instruction about features of multimodal texts, provide opportunities to practice, and reflect on how to make our representations reflect those created by career scientists.

Theme Four: Influence of Previous Instruction and Experience

In reflecting on the previous instruction and experiences that the fourth graders have had and on the findings from this study, I am now wondering how to balance providing structured lessons with student-led inquiry so that the students are able to authentically practice designing multimodal representations of their inquiry process without having to do things just like the teacher. According to the data and research reviewed for this study, it appears that both experiences were of value and can scaffold the students' learning. The question that remains is how much time should be devoted to each type of opportunity.

Theme Five: Representational Development over Time

Discovering how student-led scientific inquiry could be used to help students' develop their representational competency was a fluke, but now that I've seen its value, I want to continue to implement this type of instruction in order to allow my students to develop their literacies of science. The question is, how can I implement these student-led experiences into the normal curriculum in such a way that will allow the students to reflect, critique, and discuss the representations they are creating so that they can develop their representational competency in an authentic manner while keeping true to the integrity of the curriculum? This type of instruction is possible, but will require me to once again think creatively and look at things from a new perspective.

Future Directions

As a final piece of this discussion section, it is essential that some recommendations for future research are provided. This final section will look at these suggestions for each of the major themes.

Theme One: Support of the Scientific Learning Community

Although much has been learned from this research study about how the learning communities supported the fourth grade students during their creation of multimodal textual representations and scientific inquiry processes, much more still is not understood. Future research in this area might explore the nature of support provided by lab partners during scientific inquiry or examine how learning communities within the science lab indicative of a student's participation in the Discourse of science? More work is also necessary to understand how learning communities within a science classroom cam be used specifically and to a greater degree to scaffold the development of scientific literacy? Other considerations might take into account the nature of a scientific learning community's communication/representation of meaning during scientific inquiry or how much structure should be provided to students while working as a learning community during scientific inquiry. How does this change with the development of the student's scientific literacy and ability to participate in the Discourse of science? Much research is still needed to fully understand the role a learning community plays during scientific inquiry and how these roles support the ways scientists communicate/represent their knowledge.

Theme Two: Making Qualitative Observations and Quantitative Measurements

Further research is also needed to better understand how to better provide students with instruction on how to make qualitative and quantitative observations in science and when to use each. What is the nature of the development of how to make accurate and precise observations in science and how can we as teachers help students with this development process? How does scientific inquiry support a student's participation in the Discourse of science and the use of scientific tools and resources? Further research is needed to address these questions in more detail.

Theme Three: Use of Graphic Organizers

Although my students were able to use graphic organizers quite effectively, much more research is needed to help teachers understand the best practices for teaching students to be multimodal designers especially as it relates to a specific discipline. More work is necessary to understand the nature of the rhetorical devices inherent within each semiotic resource used to communicate meaning in science and to evaluate the relationship between the forms (or genres of representation) used and the function they serve within the discipline of science. How are these part of scientific literacy? And, what are the best ways to teach the various genres of representation as part of science pedagogy so that students can truly learn to communicate and represent meaning as members of the scientific community?

Theme Four: Influence of Previous Instruction and Experience

This study provided evidence that previous instruction influenced many of the decisions made by the students during the process of scientific inquiry, but more research is necessary to understand the extent of this previous instruction on the inquiry process itself and on the representations that resulted. The data and research from this investigation have also shown that teachers play an important role in helping students to develop the skills necessary to participate in scientific Discourse. As such, future research attention should also be given to helping teacher understand the best ways to scaffold scientific inquiry for young students and to understand how students can be engaged in a more authentic, holistic development of their inquiry skills. Teachers must also be instructed in the literacy practices necessary for the field of science as part of their science pedagogy so that they can better equip students to be designers of multimodal texts. Research into how to provide the best instruction for teachers in this area is also still necessary.

Theme Five: Representational Development over Time

The final areas of future research indicated by this study must include consideration of what type of environment best allows students to initiate the development of their own representational competency and must look at the best practices for developing a student's representational competency in science. Comparisons should also be made to understand the how the representational competency of girls differs from boys during scientific inquiry. Such studies could have significant instructional implications that could help close the gender gap in science.

Conclusion

In conclusion, this teacher action research project set out to describe the nature of multimodal representations created by fourth grade students during the process of scientific inquiry. A cross-case analysis of sixteen individual cases allowed five major themes to emerge from the data. These themes indicated that the representations created by the students: (1) were supported by the scientific learning communities; (2) demonstrated varying abilities to collect both qualitative and quantitative observations; (3) utilized a variety of graphic organizers to communicate/represent scientific information; (4) were influenced by previous instruction and experience; and (5) showed development over time. Implications for these findings may result in changes in the learning environment and pedagogy of science as teachers provide environments that support the development of learning communities; provide multiple opportunities for students to make both qualitative and quantitative measurements during scientific inquiry; provide explicit instruction into the semiotic tools used by scientists to communicate/represent meaning; and allow students the opportunity to reflect, critique, and discuss their representations so that they can learn to be more competent and fluent representors of scientific knowledge. Recommendations for future research include: learning more about the way learning communities scaffold the learning process during scientific inquiry; understanding the best practices for helping students to learn how to make qualitative and quantitative observations of the world around them; describing the best practices for teaching students to be multimodal designers of scientific knowledge; examining the effect of previous instruction on the multimodal representations created by students; and learning more about how to best develop the students representational competency in science.

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APPENDIX A

Cross Case Analysis Conclusions

	Participation in Scientific Discourse	Creating Meaning	Creating Textual Representations
Conclusion	The majority of students Table of Contents followed instructional format--many also included instructional format for citing the background information that came from other students. Several students used t-charts a tool to make comparisons or for organization purposes (own knowledge vs. other's knowledge or tool vs. its use or needs of plant vs. not needs) Students who used a data table had more consistency between their plan, procedure, and data. Organization of data was often revised--clarity of presentation improved with revision. (revised from first to second investigation or within investigation itself)--indicates understanding of importance of presenting data in a meaningful way. Students understanding was supported by a learning community--clarification of unknown scientific language/concepts, translation, and decision-making.	Scientific language--included in background information section (connecting prior instruction to lab experience and in gaining new information from other classmates)--supported by reference materials and by team members (especially for bilingual groups). Students supported each other's language development during inquiry. Several students used t-charts a tool to make comparisons or for organization purposes (own knowledge vs. other's knowledge or tool vs. its use or needs of plant vs. not needs) Students who used a data table to organize their data demonstrated a higher level of consistency between their plan, procedure, and data. This developed from investigation 1 to 2 and sometimes within an investigation as student made revisions. Some decisions about observations were limited/guided by time and ease.	Format for Table of Contents/Citations used by most students followed instructional format. T-charts and data tables were primary tools used for organizing data. Many data tables and other organization features needed headings/titles for clarity Lists of all kinds often used (bulleted, hyphenated, numbered, lists separated by lines). Sectioning, page breaks, white space also served to separate information. Many students reserved space with their data for their leaf photographs--showing forethought Representation of data often improved through revision within the investigation or from changes made from investigation 1 to 2.

	Most students choose to make a mixture qualitative and quantitative measurements. Many students understood purpose of tools selected: --some misunderstanding with lenses/loupes and graph paper --some tools used in more than one way (photographs used to show shape, size, texture, veins, etc.) Developing understanding of how to best get accurate measurements: --most quantitative tools in lab measure to nearest 0.1 unit. Student measurements measured to nearest whole number, half of a number, and went to 0.01 units which is not possible with our tools. --units of measurement showed inconsistency between metric/customary units --designations of sample or characteristic being observed were sometimes vague. Developing a problem/hypothesis, and repeating trails (calculating averages) were also incorporated into two students' observations.	Combination of both qualitative and quantitative measurements used by students. Understanding of tools/purpose of each/and accurate use of each tool is developing. --most quantitative tools in lab measure to nearest 0.1 unit. Student measurements measured to nearest whole number, half of a number, and went to 0.01 units which is not possible with our tools. --units of measurement showed inconsistency between metric/customary units --designations of sample or characteristic being observed were sometimes vague. Many tools served more than one purpose for students: --graph paper used for rubbings/area --photographs used to show veins, size, shape --leaf rubbings used to show shape, margin, size, area Reference materials were used with varying degrees of expertise: --many students attempted to use in plan and then abandoned the resources --other students used to identify characteristics to observe and then used	Size of sample often helped determine how data was to be organized. Multiple colors used for all leaf rubbings, may correspond to class instruction that color is used to organize information in science.

		common terms to describe each quality --other students used reference materials to plan investigation and to inform their data. Connections between observations and reflection questions varied. Some students used their data to inform their responses to the reflection questions while others used previous knowledge to respond to the questions. Some connections were also made between the structure/function of plants.	

APPENDIX B

IRB Approval Letters

TWU
TEXAS WOMAN'S UNIVERSITY
DENTON DALLAS HOUSTON

Institutional Review Board
Office of Research and Sponsored Programs
P.O. Box 425619, Denton, TX 76204-5619
940-898-3378 FAX 940-898-4416
e-mail: IRB@twu.edu

May 20, 2013

Ms. Christa Savely

Dear Ms. Savely:

Re: Multimodal Representations and Meaning Making in Science Inquiry (Protocol #: 17338)

The above referenced study has been reviewed by the TWU Institutional Review Board (IRB) and appears to meet our requirements for the protection of individuals' rights.

If applicable, agency approval letters must be submitted to the IRB upon receipt PRIOR to any data collection at that agency. A copy of the approved consent form with the IRB approval stamp is enclosed. Please use the consent form with the most recent approval date stamp when obtaining consent from your participants. A copy of the signed consent forms must be submitted with the request to close the study file at the completion of the study.

This approval is valid one year from May 3, 2013. Any modifications to this study must be submitted for review to the IRB using the Modification Request Form. Additionally, the IRB must be notified immediately of any unanticipated incidents. If you have any questions, please contact the TWU IRB.

Sincerely,

Vicki L Zeigler

Dr. Vicki Zeigler, Co-Chair
Institutional Review Board - Denton

cc. Dr. Connie Briggs, Department of Reading
Dr. Nancy Anderson, Department of Reading
Graduate School

TWU
TEXAS WOMAN'S UNIVERSITY
DENTON DALLAS HOUSTON

Institutional Review Board
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940-898-3378
email: IRB@twu.edu
http://www.twu.edu/irb.html

DATE: May 2, 2014

TO: Ms. Christa Savely
Department of Reading

FROM: Institutional Review Board - Denton

Re: Extension for Multimodal Representations and Meaning Making in Science Inquiry (Protocol #: 17338)

The request for an extension of your IRB approval for the above referenced study has been reviewed by the TWU Institutional Review Board (IRB) and appears to meet our requirements for the protection of individuals' rights.

If applicable, agency approval letters must be submitted to the IRB upon receipt PRIOR to any data collection at that agency. A copy of the approved consent form with the IRB approval stamp is enclosed. Please use the consent form with the most recent approval date stamp when obtaining consent from your participants. A copy of the signed consent forms must be submitted with the request to close the study file at the completion of the study.

This extension is valid one year from May 3, 2014. Any modifications to this study must be submitted for review to the IRB using the Modification Request Form. Additionally, the IRB must be notified immediately of any unanticipated incidents. All forms are located on the IRB website. If you have any questions, please contact the TWU IRB.

cc. Dr. Connie Briggs, Department of Reading
Dr. Nancy Anderson, Department of Reading
Graduate School