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Exploring Aspects of Science Literacy Demonstrated by Early Undergraduate STEM Majors through a Manuscript-Style Writing Assignment

Samantha Lynn Jusino

Dissertation submitted
to the College of Education and Human Services
at West Virginia University

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in
Interdisciplinary Education- Curriculum and Instruction

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Morgantown, West Virginia
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Keywords: Science Literacy, authentic practices, manuscript writing, STEM, undergraduate, qualitative.

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Abstract

Exploring Aspects of Science Literacy Demonstrated by Early Undergraduate STEM Majors through a Manuscript-Style Writing Assignment

Samantha Lynn Jusino

Over the past twenty years, scientific literacy amongst undergraduates has not improved despite their exposure to higher education science classes. Underlying mechanisms of science literacy development are poorly understood; however, exposure to authentic practices in science has been demonstrated as a means to fostering science literacy development. A unique approach to studying science literacy is through examining the three domains of the science literacy conceptual framework developed in this study, *Science as Access*, *Science as Process*, and *Science as a Sociopolitical Factor* and their components as they emerge through the process of writing a manuscript-style writing assignment. In this exploratory qualitative study, three research questions are addressed: 1. How do students demonstrate science literacy at different points in the writing process as they work towards completing the manuscript style writing assignment, 2. How do course artifacts related to this assignment demonstrate science literacy, and 3. How do students talk about what it means to be scientifically literate? Eight introductory STEM students participated in this study; using a combination of interviews and artifacts surrounding the manuscript-writing process and analytic techniques, a pre-structured case study was developed for each participant. A cross-case analysis was performed across all eight pre-structured cases to develop themes consistent across cases. A total of nine themes emerged from the data. The data suggested that all eight students demonstrated some aspects of science literacy. The cross-case analysis suggested that introductory STEM students have similar strengths and struggles within the *Science as Access* and *Science as Process* domains often disregarding the *Science as Sociopolitical Factor* domain. Students' perceptions also had an influence on their manuscript-style writing assignment. The implications of this study indicated that to further support science literacy in the undergraduate STEM classroom, students should be engaged in communities of practices starting in introductory courses to increase exposure to authentic practices, these authentic practices should be spread across the curriculum to challenge students to develop scientific writing norms, and the scientific writing process should be scaffolded throughout and across the curriculum and iterative in nature to promote development of science literacy.

DEDICATION

This dissertation is dedicated to my family, Mom, Dad, Stacey, and Trey. Your constant love and support throughout my education and completing my dissertation have meant more to me than you will ever know. Even though you often did not understand what I was doing, you were always there to give sage wisdom and encourage me to persist as I worked to meet my educational goals. I am forever grateful to all of you and I love you all.

To my Uncle Joe, even though you are not here to see me complete my doctorate, I know that you are looking down and proud of all of my accomplishments. You are missed every day, but I have carried your love and support with me through every step of this journey!

Table of Contents

LIST OF TABLES

LIST OF FIGURES

Acknowledgements

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Chapter 1: Introduction

While serving as a biology graduate teaching assistant (GTA), I taught Introductory to Physiology lab for multiple semesters. A large part of the curriculum of this class is to write laboratory reports following disciplinary conventions, thus resulting in a manuscript style laboratory report. Throughout these multiple offerings, I began to notice that students seemed to be writing to the demands of the rubric and not necessarily to effectively communicate their findings in a convincing and meaningful argument. As an instructor, I was interested in ensuring that my students understood not only the scientific content being taught but also if they could apply these concepts in a larger context or broader significance. Their writing demonstrated that although they might understand the concepts being taught, they were having difficulty connecting the content to a broader significance. I also noticed that students often time struggled finding and correctly using sources. It was then that I started to understand the complexities and nuances of scientific writing. This sparked an interest in understanding undergraduate students' science literacy, and more an interest in understanding how they are writing their papers and using the literature to support their arguments with the hope of being able to better support them.

In a small pilot study, I started to explore undergraduate students' writing in an introductory laboratory course. Using a stimulated recall interview, I interviewed three students about their writing process, I asked them to think out loud and reflect on their writing process for each section of the manuscript style lab report. The results suggested that while students were using the primary literature, they had difficulty sourcing information and incorporating it into their arguments. For example, they often cited from the introduction of the article as opposed to the results. Furthermore, students assumed that if an article was published in a journal then the article must be credible. While the students were correct in looking for primary literature in peer-reviewed journals; they were not able to gauge an article for credibility. Moreover, while students were able start their arguments off broadly, the students lacked the proper discourse to connect their research to a broader significance despite a clear agricultural tie to the experiment, which was on plant nutrition, and applicable to the geographical region. Lastly, students were writing to the expectation of the assignment and meeting the conventions set forth in the rubric; and, the students reported writing to meet the conventions in the field as opposed to writing to communicate their science. The same trends that I noticed in the classroom emerged during the pilot study.

Essentially, I came to understand that while these trends and pilot study results were focused on a product of students' writing process in a laboratory-based course, the larger issue was not necessarily whether students could write these manuscript style lab reports, but rather, it was whether they demonstrated aspects of science literacy in their writing. I therefore began to think about how science literacy is defined in the literature, how writing in science is connected to science literacy, and how I could examine undergraduate students' writing in ways that gave me insight into aspects of their science literacy. In order to understand how students are demonstrating aspects of science literacy through writing, it is critical to think about how they are interacting with the overall authentic science process itself. How do students define science literacy? How do students conceptualize scientific ideas in order to develop research proposals? How do they negotiate primary literature in order to construct arguments? Can they enter into the literature and comprehend it and use it effectively? Can they differ between science and pseudoscience? Do they understand how to generate hypothesis and develop methods in order to test their hypotheses? Can they analyze data? Can they interpret data? Can they link their results to the literature? Can they address the broader significance of their research and find the sociopolitical connection? Are they able to address the sociopolitical connection of their science? Clearly, there are many unanswered questions around science literacy and authentic science writing. The purpose of this dissertation work is to begin exploring some of these questions and conduct research in order to further our understanding of how students demonstrate science literacy through authentic writing activities in the undergraduate biology lab setting.

Statement of the Problem:

Science literacy, a term that is used frequently by researchers has proved challenging to definitively conceptualize and currently a number of diverse definitions exist (DeBore, 2000; Holbrook & Rannikmae, 2009; OECD, PISA, 2000). While it may be difficult to reach consensus regarding the definition of science literacy, researchers do agree that it is critical to develop this disciplinary literacy in the classroom. One approach to developing science literacy is to engage students in authentic science practices.

Over the past 20 years, K-16 educational reform initiatives in the United States and their related policies have pushed to increase the overall scientific knowledge base of US citizens (Association for Advancement of Science (AAAS), 2011; Howard Hughes Medical Institute (HHMI), 2000; President's Council of Advisor on Science and Technology (PCAST) 2010, 2012)—in other words, to increase science literacy. These reform initiatives and policies involve engaging K-16 students in authentic disciplinary practices.

In response to achieving the goal of creating scientifically literate students, researchers have developed curricular changes spanning the K-16 classroom, including the creation of Next Generation Science Standards (NGSS 2013). The new standards are designed to bring authentic scientific practices into the classroom by integrating these practices with specific science content knowledge and scientific explanations. Additionally, the new standards allow students to engage in scientific inquiry and argumentation.

This push for incorporating authentic scientific practices is also seen at the undergraduate level; however, it is often reserved for upperclassman who have already self-selected into the major. For example, scientific writing/communication is studied in small journal club seminar courses with low enrolment, at the 300-400 level (Brownell et. al, 2013). However, it has been suggested that engaging introductory undergraduates in authentic practices not only improves retention of students but also increases enthusiasm for science (Auchincloss et al., 2014).

While we know that entering undergraduates in introductory level courses have not necessarily developed the discursive practices to engage in authentic research practices (Hewings, 2005), this does not mean that they cannot engage in authentic research in meaningful ways. Authentic practice in the introductory undergraduate classroom might be used not only to address the legislative concerns of creating a scientifically literate society but also provide a context in which to examine the current state of science literacy among undergraduate students in the introductory biology laboratory.

Purpose of Study:

Prior work has shown that integrating authentic practices—including authentic disciplinary practices in writing and communicating—into the classroom better supports students in becoming scientifically literate (Brownell & Kloser 2015; Auchincloss et al., 2014). Providing opportunities for undergraduate students to employ authentic practices (i.e. a course based undergraduate research experience (CURE); authentic writing assignments) in the introductory laboratory, can improve the overall experience that an introductory student might have, such as developing mentorships with faculty, improving attitudes towards science thus leading to higher retention in the major, and exposing a greater population of students to authentic practices in research. (Auchincloss et al., 2014). For example, Brownell & Kloser (2015) suggest that these authentic research experiences expose a larger, more diverse, student population to research opportunities as opposed to the traditional research opportunities that are limited, such as conducting independent research in a faculty member's lab. Secondly, integrating authentic practices in introductory laboratory courses can also increase retention by supporting underrepresented minorities and women to persist in science due to the collaborative nature of this work and the ability to meet mentors and form mentorship relationships (Aushincloss et al. 2014; Carter, Mandell, & Maton 2009; Hippel et al. 1998; Russell, Hancock, & McCullough 2007). Thirdly, using an authentic approach has been shown to increase mastery of the scientific content, increase interest in science research, and increase critical thinking skills (Harrison, Dunbar, Ratmansky, Boyd, & Lopatto, 2011). Lastly, by introducing introductory students to authentic research experiences there can be impact on their attitudes towards scientific research. For example, Harrison and colleagues (2011) found that students reported more enthusiasm when they were able to work like actual scientists do in their freshman course.

While the idea of integrating authentic practices into the classroom has been suggested to increase science literacy, one authentic practice that has not been readily studied at the introductory level is manuscript style writing. This level of communicating one's scientific work is often studied at the advanced levels where students are thought to have developed the scientific discourse and jargon necessary to properly communicate in the field (Brownell et al. 2013). However, if engaging students in authentic practices, such as course based undergraduate research opportunities that include authentic science writing, are key to developing science literacy, then it is equally important to understand how science literacy emerges in authentic writing assignments in the introductory course. This is the purpose of this dissertation work.

Significance of Study:

It seems many researchers, policy makers, and educators alike assume that engaging in authentic science writing can support undergraduate students in becoming scientifically literate. Yet this assumption has not been tested. The question remains whether manuscript-style writing assignments in introductory science laboratory courses do indeed provide a context in which undergraduate students develop their science literacy. This dissertation study is a first step in examining this assumption as it seeks to understand whether aspects of science literacy are demonstrated in an authentic writing assignment in an introductory lab-based course. This research will provide insight into whether and how through their writing, students interact with the literature, using it to develop arguments, demonstrate how they conduct, analyze, and interpret data, and explain how their science connects to a broader societal significance. This research will also provide insight into how science literacy may not be supported in these authentic writing practices. These insights can therefore inform further course design and curriculum development at the undergraduate level in order to create a more scientifically literate student population.

Conceptual Framework and Methodology:

This dissertation study is an exploratory study examining the scope of science literacy as it is demonstrated in a writing assignment in an introductory undergraduate STEM classroom. It uses an authentic practice, manuscript style writing, to explore aspects of students' science literacy. I consider science literacy to be a multidimensional construct that incorporates the ability to access science information, have a fundamental understanding of the scientific method, and recognize the larger sociopolitical factors that influence science. This framework draws on two theoretical constructs: Hurd's (1998) construct of 25 criteria a scientifically literate person would have and Miller's (1983) construct involving the idea of multidimensionality of science literacy. In communicating their ideas and discoveries, scientists include all three of these aspects in their manuscripts reporting on work that is completed in the laboratory. This should be the case for undergraduate students' manuscript-style writing of their work in the science lab. For example, in such as assignment, one would expect to see students interacting with the literature in the introduction and discussion sections of a manuscript; knowledge of the scientific method would be present in the methods and results sections; and links to larger sociopolitical issues would be present in the introduction and discussion sections as such issues relate to the broader context in which a student might situate their experiment.

Therefore, by studying students' manuscript style writing in an introductory undergraduate STEM course, we can gain insight into what aspects of science literacy emerge as defined by the three domains of science literacy in my framework. In addition to understanding what aspects of science literacy emerges through the writing process, this study will also gain insight into how students are defining science literacy and if their definition of science literacy is supported in their writing process.

A Land Grant institution in Appalachia served as the context for this dissertation study during the Summer of 2017. Participants were recruited from two sections of an introductory biology course laboratory (Introduction to Physiology) intended for STEM majors. The students in this course span a variety of majors (i.e. biology, chemistry, exercise physiology, biochemistry, and psychology). This course is the second course in the introductory biology sequence. Students enrolled in the course were mostly White with limited minority representation, not unlike the population of the state this institution serves.

Biology graduate teaching assistants (GTAs) instructed the laboratories. The GTAs guided students through a plant nutrition module helping them to develop research proposals, develop a testable hypothesis, design experiments to test that hypothesis, carry out the experiment, analyze the data, and write a manuscript style lab report. The authentic manuscript style lab report is the focus of this study and was a part of the existing curriculum for the course. While I have served as a GTA for this course in the past, I did not do so during the time data was collected (Summer 2017).

Using a combination of three research methods-reflections, think aloud protocols, and stimulated recall interviews-this study explores aspects of eight undergraduate STEM students' science literacy that emerges in and is demonstrated through their writing of an authentic manuscript style writing assignment along with their definition of science literacy. Furthermore, in order to provide more complete understanding of these aspects, course artifacts are analyzed for science literacy as well. This study attempts to answer the following research questions:

1. How do students demonstrate science literacy at different points in the writing process as they work towards completing the manuscript style writing assignment?
2. How do course artifacts (manuscript drafts and the course rubric) related to this assignment demonstrate science literacy?
3. How do students talk about what it means to be scientifically literate?

Assumptions and Limitations of Study:

I approached this dissertation work with several assumptions. First, a major assumption of this work is that all students come into the course with a working knowledge of how to properly construct sections of the authentic writing assignment. This topic is covered in depth in the course's pre-requisite laboratory for Introduction to Physiology where students write each section of a manuscript style lab report individually and receive feedback on each section. In addition to the training provided in the pre-requisite course, in the course where this study takes place, students receive specific feedback for each section in their manuscript for the first module in the Introduction to Physiology lab on phylogenetic trees. Data for this dissertation research comes from the course's second module on plant nutrition.

This study also assumes that the questions developed in the interview protocols that I used in this research effectively probe at the aspects of science literacy present in the participants' writing. It also assumes that the interview questions were answered honestly. In addition to the interview questions that were developed, participants were asked to reflect on their writing process by describing how they engaged in this writing assignment and what their strengths and weaknesses were. This strategy assumed that being reflective of one's strengths and weaknesses in the writing process as well as how one engages in this process would provide insight into aspects of the participants' science literacy.

I served as a GTA for Introduction to Physiology laboratory during the spring semester for the past eight years, but because of this connection to the course, I chose to complete the research in a semester where I did not serve as the GTA. I made every attempt to limit personal bias throughout the collection and analysis of the research data.

Background and Role of the Researcher:

At the time of this dissertation study, I was a doctoral candidate in the Interdisciplinary Ph.D. program in Curriculum and Instruction/Literacy Studies at West Virginia University in Morgantown, West Virginia. I have a master degree in Biology with an emphasis in Neuroscience from West Virginia University and a Bachelor of Arts degree in Neuroscience from Drew University. I am currently in my 8^{th} year of teaching undergraduate biology at West Virginia University. I have taken methodology courses related to qualitative research methods and data analysis and has successfully completed training for research with human participants through the Collaborative Institutional Training Initiative.

Organization of the Study:

In the literature review, science literacy will be explored. Science literacy is a key term that is defined different ways; the theoretical framework used in this study is an attempt to define science literacy in a comprehensive manner while considering multiple constructs of science literacy. The literature review will then discuss how exposure to authentic practices in the sciences overlaps with the theoretical construct. Chapter three will outline the methodological approaches to data collection and the analytical methods applied to the data. Chapter four will present eight pre-structured case studies along with an analysis of the rubric artifact associated with the manuscript-style writing assignment. Chapter five will outline the synthesis of the nine themes developed across all eight pre-structured case studies along with implications of the current research and future directions.

Chapter 2: Literature Review

Introduction

Science literacy is a skill that is still underdeveloped spanning all educational levels and into the general public (Robertson, 2012; Bensaude-Vincent, 2001; Peters, 2013). This lack of science literacy in the general public stems from the lack of significant development of science literacy in the K-16 classroom (Lui, 2009; NAEP, 2006; NAEP, 2009; NAEP, 2015). For example, the 50th percentile for the 12th-grade students in science assessment measured at the basic level has not shown improvement from the 2009 assessment to the 2015 assessment (NAEP, 2009; NAEP, 2015). Furthermore, college graduates who have taken college-level science courses do not have an improved level of science literacy over high school graduates, and this trend has persisted for over 20 years (Impey, Buxner, Antonellis, Johnson & King, 2011). Improvement in legislation and educational standards has driven the science curriculum towards incorporating science literacy through K-16 (NGSS, 2013; AAAS, 1993; BIO 2010 Report). It has been argued by researchers that there is a need to improve science literacy amongst developing scientists, as well as non-scientists (Schueufele, 2013; Schueufele, 2014; Stilgoe, Lock & Wilsdon, 2014; vanderLinden, Leiserowitz, Feinberg, & Maibach, 2014; Shen, 1975).

Furthermore, developing science literacy is critical due to the impacts that science has on citizenship (Feinstein, 2015; Sinatra et al., 2014). For example, citizens who participate in a democratic society will vote for politicians who will make scientific decisions and from there inform policy; this policy can impact things such as air quality, healthcare, and other politically charged scientific concepts. The construct of creating a scientifically literate community is politically charged and thus, has a direct impact on citizenship (Feinstein, 2015) as it involves not only having access to science information but also making informed decisions regarding politically charged topics.

While most researchers agree that supporting science literacy across both the scientific and general public communities is indeed essential, they do not generally agree on what science literacy involves or how to define science literacy. Science literacy has become a term synonymous with many different meanings. In what follows, I will attempt to reconcile how science literacy has been conceptualized and defined in research on this construct since the term “science literacy” was coined, and I will offer a new framework conceptualizing science literacy that brings together some of this prior work.

Defining Science Literacy:

Literacy is a term that is often used in educational discourse but is often defined differently, given the context in which the term is used (Keefe & Copeland, 2011). The core context for literacy becomes more complex as it is applied to different subfields. Some subfields of literacy include: digital literacy, international literacy, critical literacy, cultural literacy, functional literacy, and science literacy, to name a few. Despite literacy being at the core of these concepts, there is not one standard definition. Knoblauch (1990) discussed four definitions of literacy concerning education.

In his first definition of literacy, Knoblauch emphasizes teaching and acquiring skills that an individual may need for daily living and require in an ever-changing technological and economic environment, that becomes more complex over time. In his second definition, Knoblauch includes cultural influences that can impact literacy. His third definition defines literacy for personal growth, for example, engaging in literature. Engaging in literature can develop one's personal literacy by promoting the success of one's understanding thus pushing forward the progress of society along with their ability to engage critically. Lastly, his fourth definition involved critical literacy; in this definition, Knoblauch highlights the importance of identifying, reading, and writing literacies that are influenced by social conditions that could impact literacy (Knoblauch 1990).

In a more recent attempt to define literacy, Keefe & Copeland (2011) set forth five core definitional principles of literacy. They include: all people are capable of acquiring literacy; literacy is a human right; literacy is not a trait that resides solely in the individual; literacy includes communication; contact and the expectation that interaction is possible for all individuals; and, literacy is the collective responsibility of every individual in the community (Keefe & Copeland, 2011). It can be seen that just defining the term literacy is a complex construct; however, when you add the term science to literacy, it adds another layer of complexity.

Science literacy is an umbrella term, like literacy, used by researchers to describe whether a student possesses a particular skill set required to be successful in the sciences. The term "science literacy" was coined during the Race to Space era of education (Hurd, 1958; Lauksch, 2000). Science literacy was first used to garner support that science is a phenomenon that is experienced in everyday life and thus, needed to be incorporated as a critical component into the American education system. Since that time, the term science literacy has evolved to have multiple meanings and has become a term that researchers often attribute different aspects or dimensions to what it means to be scientifically literate (DeBoer, 2000).

Historically, there have been two overarching ways of defining science literacy, “(1) those who advocate a central role for the knowledge of science; and (2) those who see science literacy referring to societal usefulness" (Holbrook & Rannikmae, 2009 p. 278). The first definition is a classical view of science literacy where knowing scientific content knowledge is sufficient; whereas, the latter viewpoint supports the idea of developing science literacy as a means of developing life skills. There are groups of researchers who identify with each classical definition. For example, some researchers focus on science literacy as developing literacy skills within the science classroom (Pearson, Moje, & Greenleaf, 2010). Other researchers view science literacy as understanding basic content knowledge and process skills (National Research Council, 1996; Yore & Hand, 2003; Yore, Hand, & Prain, 2002). Yore & Hand (2003) suggests that the derived definition of science literacy involves, “knowing the corpus of knowledge, whereas the fundamental sense is the ability to speak, read, and write about science.” While each of these viewpoints may have once been relevant independently, as science progresses and technology advances, thus causing paradigm shifts and creating new methods, these two definitions are no longer mutually exclusive; instead, as Miller (1983) describes, science literacy as multidimensional, involving both of these viewpoints plus more.

The Organization for Economic Co-operation and Development Programme for International Student Assessment (OECD, PISA) developed a definition of science literacy that embraces the idea of multidimensionality in 1998. They defined science literacy as “the capacity to use scientific knowledge to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity” (OECD, 2000 p.21). This definition was later modified in 2007 in order to account for the human influence on science. The new definition had three components: (1) scientific concepts (working knowledge of science content), (2) scientific processes (the scientific method), and (3) scientific situation (social and cultural influences to science).

More recently, Snow & Dibner (2016) developed a definition of science literacy that expanded outside of the science community and into the general community. They describe two perspectives of science literacy: (1) the aggregate perspective and (2) the structural perspective. The aggregate perspective compares the relationships between science content knowledge and attitudes towards science where each individual contributes to the overall science literacy of the community; the structural perspective considers a sociopolitical perspective and cultural influences that may affect science literacy. The latter perspective is still currently lacking the proper amount of research to understand its impact on building science literacy (Snow & Dibner, 2016).

While memorization of science facts is no longer sufficient for defining the science literacy of people, understanding the scientific process of how knowledge and understanding are constructed is still a relevant aspect of science literacy (Driver, Newton, & Osborne, 2000). Thus, it is unrealistic to conceptualize science literacy as a one-dimensional term where knowing science facts is sufficient to become scientifically literate. Instead, it involves multiple factors, such as understanding concepts as well as, understanding the process in which those concepts were determined (experimentally, and understanding how those concepts can interact with one another in order to inform each other (Holbrook & Rannikmae, 2009).

Most researchers have abandoned the one-dimensional definitions of science literacy (Hurd, 1958), but this has raised a new issue-*How can we precisely define and deconstruct this construct so that it can be studied?* I have attempted to address this issue by developing a conceptual framework of science literacy that draws on prior research of different aspects of science literacy, as reviewed in this chapter. For example, as a start, I drew on Hurd's (1998) definition of science literacy describing 25 criteria that a scientifically literate person would possess (Appendix A). By analyzing Hurd's (1998) 25 criteria, one can see the emergence of three categorical constructs (Yore et al., 2003), which I refer to as domains. Thinking about how one might communicate one's ideas and work in science, I grouped these categorical constructs ideas into three main domains: *Science as Access*, *Science as Process*, and *Science as a Sociopolitical Topic*. These domains became the basis of my conceptualization of science literacy. Next, I discuss Hurd's criteria that comprise each of these three domains in my conceptual framework.

Science as Access

From Hurd's list, I included the following eight criteria in my *Science as Access* domain. (In this list, I also cite other literature from research that supports some of these selected criteria).

- Distinguishes experts from the uninformed, distinguishes theory from dogma, and data from myth (Robertson, 2012; Barzilai et al., 2015).
- Recognizes that almost every facet of one's life has been influenced by science or technology (Dimopoulos & Koulaidis, 2002).

- Distinguishes science from pseudosciences such as astrology, quackery, the occult, and superstition (Impey et al., 2011).
- Recognizes that scientific concepts, laws, and theories are not rigid but essentially have an organized quality; they grow and develop; what is taught today may not have the same meaning tomorrow (Koschmann, 1996; Thoermer & Sodian, 2002).
- Distinguish evidence from propaganda, fact from fiction, sense from nonsense, and knowledge from opinions (Gormally et al., 2012; Head & Eisenberg, 2010).
- View science as social and personal a civic problem that requires a synthesis of knowledge, including natural and social science (Porter et al., 2010).
- Recognizes there is much not known in a science field and that the most significant discovery may be announced tomorrow (Kevles, 1977).
- Recognizes that short- and long-term solutions to a problem may not have the same answer (Mills, Teplitsky, Arroyo, Charmantier, Beckerm Birkhead et al., 2015).

I propose that a demonstration of these eight aspects of science literacy would require knowing the disciplinary literature, and more importantly, the ability to access the primary literature of scientific concepts being considered or studied. Therefore, I define the domain, *Science as Access*, as an individual's ability to access certain scientific information, not only in terms of physical access but also in terms of conceptual access where an individual is using knowledge to critique and/or judge information (Robertson, 2012; Porter et al., 2010; Head &

Eisenberg, 2010; Brownell et al., 2013; Gormally et al., 2012). For example, this dimension of being scientifically literate includes determining the difference between astronomy and astrology or science vs. pseudoscience.

Science as Process

From Hurd's list, I included the following seven criteria in my *Science as Process* domain. (In this list, I also cite other literature from research that supports some of these selected criteria).

- Senses how scientific research is done and how the findings are validated (Kosinkin-Collins et al., 2010).
- Knows how to analyze and process information to generate knowledge that extends beyond facts (Raths et al., 1986).
- Recognize when a cause and effect relationship cannot be drawn and understands the importance of research for its own sake as a product of a scientist's curiosity (Raths et al., 1986).
- Recognizes when one does not have enough data to make a rational decision or form a reliable judgment (Horng et al., 2013).
- Recognizes that scientific literacy is a process of acquiring, analyzing, synthesizing, coding, evaluating, and utilizing achievements in science and technology in human and social constructs (Crotwell-Timmerman et al., 2011).
- Recognizes that the immediate solution of science social problems may create a related problem later (Nelson, 2004).

- Recognizes the cumulative nature of science as an endless frontier (Kevles, 1977).

I propose that a demonstration of these seven criteria require the knowledge and ability to engage with the process of "doing" science. Therefore, I define the domain *Science as a Process* as the ability to engage in scientific practices or engage in "doing science," in order to construct a scientific understanding of phenomena (Crotwel-Timmerman et al., 2011; Timmerman & Strickland, 2009; Kosinki-Collins et al., 2010). For example, this dimension of science literacy involves being able to draw links between variables or know how to analyze data among other aspects of “doing” science.

Science as a Sociopolitical Factor

From Hurd’s list, I included the following ten criteria in my *Science as a Sociopolitical Factor* domain. (In this list, I also cite other literature from research that supports some of these selected criteria).

- Knows that science in social contexts often has dimensions in political, judicial, ethical, and sometimes moral interpretations (Dimopoulos & Koulaidis, 2002).
- Uses science knowledge where appropriate in making life and social decisions, forming judgments, resolving problems, and taking action (Grooms, Brickman, & Lutz, 2014).
- Recognizes scientific researchers as producers of knowledge and citizens as users of science knowledge (Feinstein, 2015).
- Recognizes gaps, risks, limits, and probabilities in making decisions involving knowledge of the science of technology (Dimopoulos & Koulaidis, 2002).

- Knows that science problems in personal and social contexts may have more that one “right” answer, especially problems that involve ethical, judicial, and political actions (Barzilai et al., 2015).
- Recognizes that our global economy is largely influenced by advancements in science and technology (Hurd, 1975).
- Recognizes when cultural, ethical, and moral issues are involved in resolving science-social problems (Miller, 1998).
- Recognizes the symbiotic relationships between science and technology and between science, technology, and human affairs (Feinstein, 2015).
- Recognizes that science-social problems are resolved by collaborative rather than by individual action (Lakhani, Jeppesen, Lohse, & Panetta, 2007).
- Recognizes that the immediate solution of science social problems may create a related problem later (Nelson, 2004).

I propose that a demonstration of these ten criteria requires an understanding of the idea that cultural, social, and political influences shape the science process. Therefore, I define the domain of *Science as a Sociopolitical Factor* as an individual’s ability to understand or recognize that science has social, cultural, political, economic, and moral/ethical implications (Feinstein, 2015; DeBoer, 2000; Miller, 1998; Peters, 2013; Hurd, 1975). For example, this dimension of being scientifically literate involves understanding the broader implications of medical research to the community; more research can lead to breakthroughs that can cure/treat a disease, but these findings can also elicit ethical concerns of some members of the community (i.e., stem cell therapy in treating some cancers; Snow & Dibner, 2016).

Recall that the second construct that I draw on to define science literacy is Miller's (1983) idea of multidimensionality. Miller suggests, "Civic science literacy should be conceptualized as involving three related dimensions: (1) a vocabulary of basic scientific constructs sufficient to read competing views in a newspaper or magazine, (2) an understanding of the process of nature of scientific inquiry, and (3) some level of understanding of the impact of science and technology on individuals and on society" (Miller, 1998, p. 205). This definition informed how I think about science literacy because it aligns with Hurd's 25 criteria similar to the three domains I have proposed in my conceptualization of science literacy, AND it suggests that there is a level of multidimensionality that exists in science literacy. Therefore, it is not enough to know of each of the three domains independently; but instead, to be scientifically literate, one should understand the interconnectedness between the three domains as well. Being able to draw relationships between each of the domains and understanding how each domain is in service to another is indicative of science literacy based on this conceptualization.

My conceptual model of science literacy, therefore, builds on these ideas but differs in that it aims to define science literacy as a multidimensional approach that considers multiple populations, including undergraduate biology students. I contend that each domain of science literacy cannot be learned without the influence or understanding of the other domains. It supports the idea that knowledge is not constructed in isolation, but rather, that knowledge is constructed using the cultural/social influence of time and the processes being used (Brown et al., 2005). This model also supports the claim that there is not one path to becoming scientifically literate, but instead multiple paths that are not linear but circuitous (Figure 2.1).

One can never become omniscient in one section because the knowledge, technology, and research in the sciences are continually evolving. In this regard, this model is dynamic and can support technological advancements because a skill set loosely defines each section; therefore, changes within the field, such as techniques or technology development still exist within the limits of each category. This flexibility allows for growth without altering the dimensions or domains of science literacy. Finally, it is at the intersection of these three domains, where an individual can be considered scientifically literate. It is important to note that no one individual could ever be omniscient in science; however, by being able to navigate, interpret, and apply scientific information, they will then be considered scientifically literate.

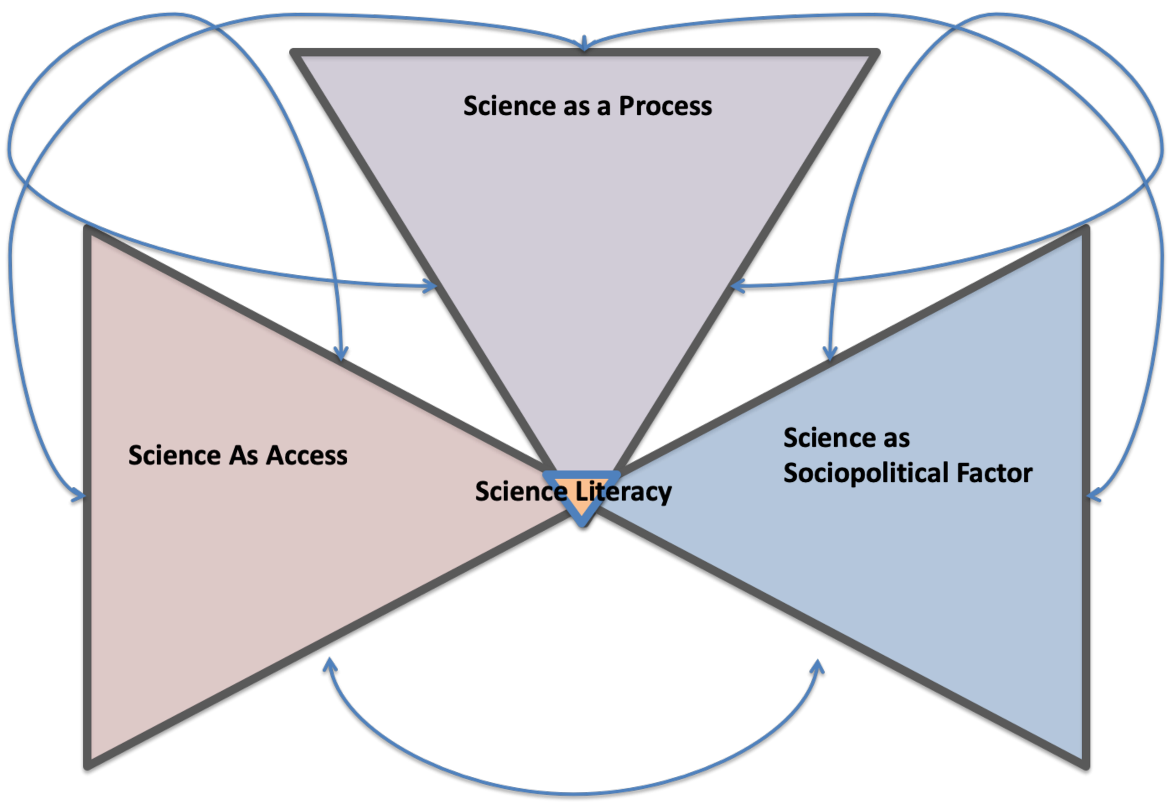

Figure 2.1: Science Literacy Figure: A proposed multidimensional approach to demonstrating science literacy

We can see that although science literacy is a frequently used term by researchers, it has proved to be challenging to conceptualize definitively. While it may be challenging to reach a consensus regarding the definition of science literacy, researchers, including myself, agree that it is critical to developing this disciplinary literacy in the classroom. One approach to developing science literacy is to engage students in authentic science practices.

Authentic Practices in Science

The debate around science literacy discussed thus far, as well as how I conceptualize this construct in my conceptual framework, certainly impacts how science literacy is demonstrated and supported in the undergraduate classroom. For example, if on the one hand, science literacy is defined as public understanding of science content (DeBoer, 2000; Miller, 1998), then science content overall will be emphasized in the undergraduate course. DeBoer (2000), suggests, "scientific literacy defines what the public should know about science in order to live more effectively with respect to the natural world" (p. 594). This research places emphasis on science content and implies that science literacy can be developed through taking science coursework; however, research has suggested that merely enrolling and completing a college science course does not increase science literacy over those who have only completed the high school science curriculum (Impey et al., 2011). This would support the idea that solely reading informational texts such as textbooks cannot develop science literacy.

If science literacy involves other critical components such as writing and interpretive skills (Norris & Phillips, 2003; Hand et al., 2003), then these other components together with content should be highlighted in the undergraduate science curriculum. Norris & Phillips (2003) argue, "If scientific literacy is conceived only as knowledge of the substantive content of science, there is a risk that is striving to learn the elements of that content will define our goals without any appreciations for the interconnection among the elements of content, their sources, and their implications" (p. 236). This argument aligns with the use of authentic writing activities in the classroom (Glynn & Muth, 1994) in which students understand the content, process, and interpretation of what the experimental science means; this also aligns with my conceptual framework of science literacy. Furthermore, Mason and Boscolo (2000) suggest that science literacy is steeped with "a very sophisticated set of cognitive and metacognitive behaviors." It is the integration of both scientific concepts, process skills, metacognitive processes, critical reasoning skills, and sociocultural influence of science that supports science literacy (Cavagnetto, 2011). This integration of these skills is aligned with the conceptual framework of this study: *Science as Access* is demonstrative of concepts and scientific information, *Science as Process* is demonstrative of process skills and experimental techniques, *Science as a Sociopolitical Factor* is demonstrative of sociocultural influence of science and the metacognitive processes can be seen in the interconnectedness of the domains and within the domains as knowledge shifts and grows.

Trying to incorporate science literacy skills in the K-16 classroom is not an easy task. Over the past 20 years, K-16 educational reform initiatives in the United States and their related policies have pushed to increase the overall scientific knowledge base of US citizens Association for Advancement of Science [AAAS], 2011; Howard Hughes Medical Institute [HHMI], 2000; President's Council of Advisor on Science and Technology [PCAST] 2010, 2012)—in other words, to increase science literacy. These reform initiatives and policies involve engaging K-16 students in authentic disciplinary practices. While these initiatives are being updated and incorporated into curricular standards across K-16, there is still a disconnect between the theory and praxis.

In response to achieving the goal of creating scientifically literate students, researchers have developed curricular changes spanning the K-12 classroom, including the creation of Next Generation Science Standards (NGSS, 2013). The new standards are designed to bring authentic scientific practices into the classroom by integrating engagement in such practices while constructing an understanding of specific science content knowledge and scientific explanations. Additionally, the new standards allow students to engage in scientific inquiry and argumentation. In order to allow our students to engage in science as scientists would, we have to provide teachers the ability to engage in those same science practices, including scientific writing in authentic contexts; however, we often see that authentic writing experiences in K-12 are limited (Shosh & Zales, 2005; Gallavan; Bowles, & Young, 2012; Purcell-Gates, Duke, & Martineau, 2007).

Just as we have seen this shift in the K-12 classroom with the adoption of NGSS, there have also been curricular changes in the undergraduate biology curriculum. More specifically, at the undergraduate curricular level, in some contexts (but not all), we have seen a substantive transition from traditional "cookbook" laboratories to inquiry-based laboratories to course-based undergraduate research experiences (CURES) (Auchincloss, Laursen, Branchaw, Egan, Graham, Hanauer, et al., 2014). Research has demonstrated, "the traditional experience in lab classes, with "cookbook" experiments in which students follow a predetermined methodology and then prepare an artificial scientific report, is not sufficient for teaching scientific content or the process of science (Spell, Guinan, Miller, & Beck, 2014, p. 102). The goal of shifting the curriculum is to develop a more authentic science experience and to expose a broader group of students to these opportunities early on in their academic careers, for example, during their introductory biology courses.

The traditional style of laboratory instruction for an undergraduate STEM classroom is referred to as the expository laboratory or more colloquially as a "cookbook" laboratory (Domin, 1999). Expository laboratories are the least authentic in that they do not incorporate the conceptualization of the research question or the design of the laboratory methods; instead, the instruction relies on a prescribed experiment with predetermined outcomes (Lagowski, 2002). The “cookbook” laboratory limits a student’s ability to engage in higher order critical thinking skills; however, this approach is widely used in large enrollment courses (Domin, 1999; Lagowski, 2002). In an attempt to more critically engage undergraduate students in the laboratory, the curriculum has shifted to an inquiry-based curriculum in alignment with educational policy reforms (Domin, 1999; Lagowski, 2002; AAAS; 1993).

The inquiry-based curriculum is student-driven and involves an inductive process that has undetermined outcomes (Domin, 1999; Nilson, 2016). This type of curriculum in the undergraduate laboratory is driven by the students’ hypotheses and methods and allows the students to interact as they would in a more authentic laboratory setting. By allowing students to drive the investigation, the instructors engage their students in higher order thinking processes including hypothesizing, explaining, criticizing, analyzing, judging evidence, inventing, and evaluating arguments (Domin, 1999; Raths, Wasserman, Jonas, & Rothstein, 1986). Furthermore, Weaver, Russel, & Wink (2008) outline the activities associated with inquiry-based curriculum including “making observations, formulating questions, gathering evidence in a reproducible manner, making scientific claims based on evidence and existing scientific knowledge, communicating results, and revising the explanation or revisiting the experiment based on feedback and critique from the community" (p. 577). These practices align with the science literacy conceptual framework developed in this dissertation work; more specifically, they align with the *Science as Process* domain of science literacy. In addition to developing scientific research skills, the inquiry-driven curriculum also develops scientific writing skills by allowing students to learn to not only think in inquiry-based ways but also to write in inquiry-based ways (Beck, Butler, & Burke da Silva, 2014). The inquiry-based curriculum in the science laboratory thus begins to address concerns of science literacy development previously discussed by engaging students in more authentic science practices, including authentic science writing practices.

Another and more recent curricular shift in undergraduate science education involves course-based undergraduate research opportunities (CURES). The goal of CURES is to expose a greater diversity of students to authentic research experiences most often limited to upper divisional courses with small enrolment (Brownell and Kloser, 2015) or individual student opportunities to work in research laboratories with primary investigators, also a limited opportunity. There are many affordances to using CURES instruction. CUREs can be a positive influence for supporting underrepresented minorities and women to persist in science due to the collaborative nature and the ability to form mentors and to increase retention (Aushincloss et al. 2014; Carter, Mandell, and Maton 2009; Hippel et al. 1998; Russell, Hancock, and McCullough 2007). Furthermore, CUREs have been shown to increase mastery of the scientific content, increase interest in science research, and increase critical thinking skills (Harrison, Dunbar, Ratmansky, Boyd, & Lopatto, 2011). Lastly, by introducing introductory students to authentic research experiences, there can impact on their attitudes towards scientific research. For example, Harrison and colleagues (2011) found that students reported enthusiasm when they were able to work as a scientist in their freshman course.

Authentic experiences, such as those supported in an inquiry-based curriculum and in a CURES opportunity, in biology include tasks that involve: (1) using scientific practices (asking questions, developing hypotheses, designing studies, analyzing data, critiquing interpretations and arguments, and communicating findings), (2) discovery (outcome is unknown to students and instructor), (3) broadly relevant or important work (students are tasked with building on current scientific knowledge), (4) collaboration (students work in groups to contribute different skills towards solving the problem), and (5) iteration (mimics the inherently iterative practice of science, includes peer review) (Aushincloss et al. 2014). When students are introduced to these types of curriculum early on in their education, specifically, during their first-year introductory STEM courses, they start to engage in authentic communities of disciplinary practice (Aushincloss et al. 2014). However, there are current curricular barriers, such as time, resource availability, scalability that have limited implementation of inquiry based and CURES approaches in large enrollment courses (Bangera & Brownell, 2014; Shortlidge, Bangera, & Brownell, 2016).

Communities of practice have been traditionally defined as professional communities with disciplinary norms that its members process and enact (Lave and Wenger, 1991; Buysse, Sparkman, & Wesley, 2003). Barab and Duffy (2000) further define communities of practice as an individual's development of self through participation within a community of practice. It is through involvement in these communities of practice that students are able to train and engage students in disciplinary practices through meaningful activities within those communities (Handley, Sturdy, Fincham & Clark, 2006). Furthermore, research suggests that these communities of practice can be aligned with authentic research opportunities (Buysse, Sparkman, & Wesley, 2003). Drawing on both the research on communities of practice and on the current curricular shifts in undergraduate science laboratory education as reviewed thus far, one can conclude that engaging students in disciplinary communities of practice early on in their education is important to the development of science literacy. The idea that this engagement can help students develop practices of scientists as they interact in authentic community practices such as research and scientific manuscript writing conventions.

While there have been curricular shifts in undergraduate STEM laboratory instruction, moving instruction away from traditional cookbook laboratories towards more authentic science experiences, one authentic practice that merits more research at the introductory level is authentic writing practices in STEM laboratory courses. An authentic writing practice, more specifically as it pertains to this research context, writing a manuscript style laboratory report, involves culmination of the laboratory work, which aligns with the curricular shifts, that students complete in the classroom. Manuscript writing is a space where students are able to not only consolidate their understanding of the science content knowledge, but also, it is a space that allows for the opportunity to make/develop connections between the laboratory data and the broader significance of their science, both of which are hallmarks of science literacy, aligning with all three domains of the science literacy conceptual framework guiding this research.

Manuscript Writing

A primary aspect of literacy, in general, involves the ability to write and communicate (Hand et al., 2003; Campbell, Kaunda, Allie, Buffler, & Lubben, 2000). In science learning contexts specifically, researchers have argued that writing is a critical component of communication because it provides students a context to reflect and consolidate understandings of not only laboratory experiments, but also the concepts taught in lecture (Yore, Hand, & Prain, 2002; Keys, 1999; Rivard, 1994). For example, Yore and colleagues (2002) argue that writing in science demands attention to patterns, sequence, and detail and thereby supports the connectedness of claims. Further, they contend this connectedness is necessary for building a scientific argument yet; it is not easily done in an oral context. Therefore, it is vital to use writing as a venue to do so (Yore et al., 2003).

Undergraduate students in introductory science courses are often tasked to synthesize their conceptual understanding along with their experimental results in the form of a manuscript style-writing format. By providing students the opportunity to synthesize their understanding in an authentic writing assignment, students are able to not only use writing as a means of synthesizing the content learned in class and the laboratory but also develop necessary technical skills for their field (Brown et al., 2005; Yore et al., 2002). For example, Yore and colleagues (2002) state that most science writing activities are used as a method for synthesizing knowledge at all levels of education. Furthermore, Brown and colleagues (2005) suggest that developing a discursive identity in science is critical for developing science literacy and writing can serve to develop that identity. Furthermore, through iterative practice and engagement in the community of practice (i.e., authentic writing in the sciences), this discursive identity takes shape (Lemke, 1997). Developing this discursive identity cannot be developed individually but rather in a collaborative setting through interactions of different members of these communities, including peers and instructors.

A part of developing science literacy and developing that discursive identity means learning to talk science. According to Lemke (1990), "'talking science' means observing, describing, comparing, classifying, analyzing, discussing, hypothesize, theorizing, questioning, challenging, arguing, designing experiments, following procedures, writing, lecturing, and teaching in and through the language of science" (p. 16). A vehicle that could combine all of these aspects into one space is authentic manuscript style writing assignments. For example, developing arguments using other science and discussing this other science can be seen in the *Science as Access* domain; hypothesizing, observing, and analyzing can be seen in the *Science as Process* domain; and developing new questions and their significance can be seen in the *Science as a Sociopolitical* domain. All three of these overlays with manuscript writing; *Science as Access* can be made evident in the introduction and discussion sections of the manuscript, *Science as a Process* can be made evident the introduction, methods, results, and discussion sections, and *Science as a Sociopolitical factor* can be made evident in the introduction and discussion sections.

One aspect of writing in the laboratory is the development of cognitive and metacognitive behaviors. Hofstein and Lunetta (2003) define laboratory learning as "learning science with special attention to scholarship associated with models of learning, argumentation and the scientific justification of assertions, students' attitudes, conditions for effective learning, students' perceptions of the learning environment, social interaction, and differences in learning styles and cognitive abilities" (pg. 31). This overlaps with the proposed model of science literacy. Students would engage in the writing process, thus forming scientific arguments within the introduction and discussion sections; students would then use their data to justify their claims. Brownell and Kloser (2015) further suggest that "the construction and evaluation of theoretical models, the analysis and interpretation of data, the development of evidence-based arguments and the communication of those arguments represent foundational practices" (pg. 530). Roughly translated, this is what the manuscript style writing assignment space provides. Furthermore, being able to communicate within science effectively is a core scientific practice (Brownell & Kloser, 2015); therefore, students who interact within settings that employ authentic research practices should not only be exposed to authentic research experiences but also authentic scientific communication processes. I contend that although students may have limited disciplinary discourse as defined by the ability to communicate both in oral contexts and as demonstrated through text (Kondrateve & Ibatulina, 2016), with immersion into authentic scientific practices early in their coursework, specifically, authentic scientific writing practices, undergraduate introductory biology students will be able to demonstrate aspects of science literacy.

Some discourse limitations, such as mastery of vocabulary, dissecting a primary research article, or writing a manuscript style laboratory report can be mitigated through physically occupying a clinical space, such as through instruction, guidance, and scaffolding of the authentic practices and their components (Vygotsky, 1978; Nilson, 2016). Scaffolding provides students the guidance to develop skills towards expert practices (Nilson, 2016). A vital component of the authentic practice curriculum is iteration and collaboration. In the laboratory setting, iteration can be seen in multiple contexts, including repeated experiments, repeated exercises on analyzing and interpreting data, and multiple drafts of the manuscript. Collaboration is also a common practice in the introductory lab where students work in small groups or classes to complete experiments and also when they engage in peer review. I would argue that iteration is not only a process for developing tangible laboratory skills, but also for developing the discourse and conventions within the field. By providing students the space in which they can develop these discursive practices in an introductory laboratory, allow students to engage authentically in critical practice, thus providing multiple iterations of this practice over a semester. Writing in presentation style publications or manuscript writing is an authentic critical discursive practice in science (Spell et al., 2014).

By, scaffolding the process of “talking science”, or in the case of this dissertation work “writing science” can help students develop their discursive identity. Feedback and peer review of one’s writing in science can be a means of scaffolding in the classroom (Lundstrom & Baker, 2009). Lundstrom & Baker (2009) describe peer review as:

> “An important activity which allows writing teachers to help their students receive more feedback on their papers as well as give students practice with a range of skills important in the development of language and writing ability, such as meaningful interactions with peers, a greater exposure to ideas, and new perspectives on the writing process” (p. 30).

In addition to peer review being a means for providing feedback and scaffolding, it is also an authentic practice in science. When students engage in peer review, they not only engage in an authentic practice and talk science, but also support each other in restructuring their ideas around their paper topic through discussion with a peer (Richmond & Striley, 1996).

Currently, as seen across the literature reviewed in this chapter, research does support the argument that engagement with authentic science practices increases students' science literacy, there is little research examining whether and how science literacy shows up in authentic writing experiences specifically (Campbell et al., 2000; Keys, 1999). Furthermore, we as a field do not understand the underlying science literacy processes that emerge in introductory undergraduate students as they are using writing as a vehicle to construct arguments and synthesize information from both the laboratory and the literature.

The interface of science literacy and authentic science practices, such as manuscript writing, is conceived in the conceptual framework developed for this dissertation work. The conceptual framework not only attempts to consolidate the many definitions of science literacy but also aligns with the traditional sections of the authentic manuscript, introduction, methods, results, and discussion sections. *Science as Access* is made evident in the introduction and discussion sections, *Science as Process* is made evident in the introduction, methods, results, and discussion section, and *Science as a Sociopolitical Factor* are made evident in the introduction and discussion sections. The following sections will align science literacy and authentic writing practices, along with the three domains.

Science as Access:

The Association of College and Research Libraries (ACRL) defines literacy as "an individual being able to locate, evaluate, and use the needed information" (ACRL, 2000) effectively. In science, an aspect of literacy involves being able to read primary literature and extrapolate meaning from the information presented (Robertson, 2012). However, prior work demonstrates that undergraduate science students can read primary literature, but they often do not process the information that the papers present because they are not able to comprehend or extrapolate meaning from the information presented (Robertson, 2012). Robertson (2012) further investigated this in a journal club workshop. It was found that explicit instruction and guided reading of primary literature improved not only the students' ability to read primary literature but also improved their overall confidence in reading those types of articles. While this study demonstrated that explicit instruction helps students access the primary literature, often time, finding, reading, and using the primary literature is not a skill that explicitly addressed in the undergraduate classroom or laboratory (Robertson, 2012).

Other researchers argue that it is critical for students to be able to (1) read, dissect, and analyze the data presented in primary literature (Brownell, Price, & Steinman, 2013), (2) apply that information to specific applications, such as everyday life contexts (Eisenhart, Finkel, & Marion, 1996), and (3) support and/or build arguments based on a robust understanding of the results and implications of both published and their own experiments (Bazerman, 1998; Hand et al., 2003; Brown et al., 2015).

Porter and colleagues (2010) describe science literacy in the undergraduate classroom as the intersection of information literacy skills (IL) (ability to find information; for example, finding an original research article and being able to classify it as primary or secondary) and science literacy (SL) skills. For example, using a method known as SMILE, these researchers were able to introduce undergraduate students to both IL skills and SL skills, and they described the interaction concerning six cognitive processes (remember, understand, apply, analyze, evaluate, and create). In their model, there is a clear overlap of IL and SL skills in the lower order cognitive processes such as remember and understand; however, as students progressed into higher order cognitive processes, the need for IL is not applicable, whereas SL skills are critical (Porter et al., 2010). The SMILE method aided in scaffolding the skills necessary to meet the requirements of the *Science as Access* component of science literacy by having the students interact with primary literature and explicitly teach the students the skills necessary to read and critique it.

Because students tend not to understand the primary literature, they often rely on empiricism and cannot relate the experiment to the theoretical understanding (Antonellis et al., 2012). For example, students reviewing primary literature might only focus on the introduction of a research article as opposed to the results and discussion and thus miss the main point of the research, the conclusion. As a consequence, for example, students will rely on just presenting their data/results but will not be able to interpret what they mean or relate that meaning to other studies in the field. I contend that this is an essential component of science literacy because regardless of whether a student can understand the experimental techniques needed to solve a particular problem if they cannot extrapolate meaning from those techniques, those results are useless towards constructing a conceptual understanding and thus demonstrate science literacy.

Pearson and colleagues (2010), cite research by Moje (2004) where middle and high school students read both scientific texts and lay texts, translated them, and then participated in peer review to compare their written explanation of the texts to the hypothesis they wrote. When peer review was completed, students not only produced more scientifically accurate explanations, both rhetorically and content but also increased in their overall amount of scientific content-based knowledge demonstrated. This would suggest that interacting with their peers, not only allows them to understand better the science being discussed, but it also allows them to engage in authentic scientific practices such as peer review.

It is important to understand how college students are accessing information, through the primary literature, in order to construct scientific arguments. The *Science as Access* domain posits that students must critique and adequately interpret and engage with the primary literature. Prior research contends that this often proves to be a difficult task for undergraduate students to accomplish (Gawalt, 2011). Part of critiquing and interpreting primary literature is synthesizing it to formulate scientific arguments.

Science Argumentation. Science argumentation has been shaped mainly by classical argumentation literature. The classical argumentation considers multiple aspects associated with science literacy, including, reading, comprehending the reading, and evaluation of evidence. At the heart of argumentation is Toulmin's argumentative structure (Toulmin et al., 1984). Wolfe (2011) describes Toulmin's model as "a jurisprudence model of argumentation [which] conceives of arguments as claims supported by data. Claims and data are connected by warrants, broad universal statements authorizing the link between claims and data" (p. 195). Toulmin's classical argument structure, or modification to the classical structure, seems to be an underlying approach in which research about argumentation is conducted in the field.

Introductory undergraduate students in the sciences may not have a vast discipline-specific vocabulary; however, by engaging them in authentic practices, students can start to develop the discourse of the field and ultimately learn through engagement how to "talk science" (Lemke, 1990) and construct arguments. Apart from the necessary vocabulary discourse, students also have to become familiar with the language structure of the scientific argument. Specifically, "scientific discourse that is particularly relevant in the present context is the explanatory argument and the particular linguistic features of it, including claims, scientific principles, and descriptions of methods used to establish the reliability of the processes used to create the evidence" (Goldman et al., 2016, p.15). It is not enough for a student to read an argument and make meaning of it; instead, they also need to have access to the discourse of the field connected to the structure of a scientific argument.

If we think about Toulmin's model (Fukawa-Connelly, 2014):

- The data provides: the foundation upon which the argument is based.
- The conclusion articulates that which is being argued.
- The warrant justifies the relationship between the data and the conclusion.
- The backing supports the warrant by suggesting why it is valid, or, put another way, explains the permissibility of the warrant.
- The modal qualifier expresses a degree of confidence in the conclusion.
- The rebuttal states conditions under which the conclusion would not hold.

This structure can relate to the overall structure of how students should be reading primary literature to understand not only other researchers' arguments but also to help model how they should structure their own arguments. For example, it is not enough to utilize your personal beliefs and understanding in scientific argumentation, but rather, one must reconcile data, representation used to convey science meaning and furthermore, they must reconcile and synthesize a variety of knowledge, especially when constructing their scientific arguments (Goldman, Ko, Greenleaf, & Brown, 2018).

While research has been conducted exploring how students can read and evaluate arguments, is there a difference between when a student has to use cognitive ability in order to evaluate the argument as opposed to when they have to construct an argument? Takao & Kelly (2003) assessed the evidence used in the scientific writing of university-level physics students. The context in which they studied was a writing intensive physics course. This study suggested, "The task of formulating scientific arguments requires abstraction from specific data to make theoretical claims (Takao & Kelly, 2003, p. 359). They go on to say that students need to have a working knowledge of their own and other's writing practices in order to build cogent arguments. Scaffolding of this task can be accomplished through the drafting process and peer review process, as it is beneficial to provide feedback to students and provide them the opportunity to address the feedback.

Argumentation is a necessary skill for scientists to have and to develop science literacy as previously defined. There are multiple purposes for developing argumentation skills in undergraduate introductory science courses including: (1) supporting access to the cognitive and metacognitive process characterizing expert performance and modeling for students, (2) developing communicative competency and development of critical thinking, (3) developing scientific literacy and allowing students to talk and write the language of science, (4) supporting enculturation of science culture, and (5) supporting development of reasoning and decision making based on reasoning (Jimenez-Aleixandre & Erduran, 2007).

In congruence with my conceptual framework presented earlier, science argumentation is a critical component of the *Science as Access* domain along with connections to the *Science as Sociopolitical Factor* domain. For example, a student would begin their argument with a broader significance driving the intent of their experiment in the introduction using the literature to guide their claims; likewise, in the discussion, the students would then continue their argument, this time using their data to discuss their findings again tying them back to their sociopolitical topic. According to Garcia-Mila & Andersen (2007), “scientific discursive practices such as assessing alternatives, weighing evidence, interpreting texts, and evaluating the potential validity of scientific claims are all seen as essential components in constructing scientific arguments” (p. 30).

In sum, researchers agree that argumentation skills are underdeveloped and critical for students’ scientific literacy. Researchers also agree that students often lack the rhetorical and discourse skills necessary to effectively utilize the literature as an expert might (van Lacum, Ossevoort, Buikema, & Goedhart, 2012). I contend that although the students may not have the rhetorical and discourse skills to use the literature as experts would effectively, they could begin to build skill around this domain of science literacy and use primary literature in their writing if they are given the opportunity to engage in manuscript-style writing in their undergraduate introductory laboratory courses.

Science as Process:

The scientific method is commonly discussed across curricular contexts spanning K-16 education (AAAS, 1993; NRC, 1994; BIO 2010). In regards to undergraduate education, traditional laboratories or “cookbook” laboratories have limitations on developing science literacy as they fail to engage students in authentic cognitive tasks, such as hypothesis and methods formation (Domin, 1999; Lagowski, 2002). Furthermore, these laboratories intend to instruct students on how to collect data and implement procedures (Domin, 1999). The outcome of this type of curriculum has shown that no meaningful learning takes place; thus, students are not learning these process skills; due to their focus on finding the "right" answer (Domin, 1999). Conversely, when students have to think about the research design of an experiment, such as in an authentic practice curriculum, like inquiry-based curriculum or CUREs, students more critically engage with the methods, analysis, and interpretation of their results (Raths et al., 1986).

When students engage critically in authentic practices, they use the language, models, methods, and symbols of scientific inquiry (Bencze & Hodson, 1999). Roth & Roychoudhury (1993) found that when students authentically interact with the scientific process in an inquiry-based curriculum, they were able to identify variables (an important disciplinary practice). Furthermore, students' interpretations of experimental results became more complex, and motivating students to generate new hypotheses. The inquiry-based curriculum also provided students the opportunity to design experiments, thus leading to more complex experiments (Domin, 1999). Finally, the inquiry-based curriculum focused less on the right answer and had more adaptability, which ultimately developed highly integrated science process skills among the students in this study.

The ability to understand and develop the experimental design speaks to both a foundational understanding of the topic being investigated and also allows students to make those meaningful interpretations and connections to society (Caygnato, 2010). Having a more sophisticated understanding of the process skills necessary to develop science literacy can be demonstrated in the authentic writing artifact. It is the bridge that connects *Science* as *Access* in the introduction and discussion section, and it also allows students to identify the more considerable broader societal impact, because that inquiry is being driven by the student, thus allowing them to interact authentically.

Science as Process involves a shift in curriculum towards more authentic practices and experiences, for example, as demonstrated by the shift in curriculum, students' exposure to more authentic practices are critical for developing higher order cognitive behaviors in scientific discourse (Bencze & Hodson, 1999; Roth & Roychoudhury, 1993; Caygnato, 2010). In addition to creating more authentic experiences, researchers have argued that participation in undergraduate research experiences develop future scientists in an authentic way (Thiry & Laursen, 2010; Linn, Palmer, Baranger, Gerard & Stone, 2015; Thiry, Weston, Laursen, & Hunter, 2012). Furthermore, they agree that these authentic experiences provide opportunities to participate in scientific communities of practices often offering students the opportunity to develop scientific discourse (Thiry & Laursen, 2010; Thiry, Weston, Laursen, & Hunter, 2012). Furthermore, they develop students' ability to critically think about science content knowledge and scientific methods, develop mentorships, provide feedback, demonstrate the iterative process of science, and allow insight into how science is conducted in research laboratories (Thiry & Laursen, 2010; Linn, Palmer, Baranger, Gerard & Stone, 2015; Thiry, Weston, Laursen, & Hunter, 2012).

While we know that these opportunities aid both in developing undergraduate students in authentic ways, these opportunities are limited due to the resources required (Linn, Palmer, Baranger, Gerard & Stone, 2015). As previously described, a shift to the CUREs curriculum allows a more diverse population of students, and, more specifically, CUREs provide students in lower divisional classes the opportunities to engage in authentic and meaningful scientific practices at a higher percentage (Linn, Palmer, Baranger, Gerard & Stone, 2015).

One such standard scientific practice that students typically engage in is data analysis; this practice is included across science standards across K-16 standards (NRC, 1996; NGSS, 2013; BIO, 2010). Regardless of the setting, however, students across educational levels have difficulty interpreting data (Kanari & Millar, 2004; Picone, Rhode, Hyatt, & Parshall, 2007; Linn, Palmer, Baranger, Gerard & Stone, 2015). Kanari and Millar (2004) found that students across age ranges had difficulty recognizing and reasoning through the idea that "measurements are inevitably subjected to uncertainty" (p. 767). Furthermore, they had difficulty interpreting data where error was a factor (Kanari & Millar, 2004). Linn and colleagues (2015) found that students who engage in undergraduate research experiences do not often interpret data, rather they often carry out the experiment; thus, further limiting their ability to interpret data. Furthermore, students have difficulty finding patterns or trends in data, understanding significance of statistical data with noise, and interpreting graphical representation of data (Picone, Rhode, Hyatt, & Parshall, 2007).

Yet participating in normal science coursework in the curriculum and undergraduate research experiences have not demonstrated an increase in one's ability to interpret data (Kanari & Millar, 2004; Picone, Rhode, Hyatt, & Parshall, 2007; Linn, Palmer, Baranger, Gerard & Stone, 2015) In an attempt to address concerns in students' abilities to interpret data, Brownell and colleagues (2015), explored how engaging students in a CURE curriculum in large enrollment courses affected the students' abilities to interpret data. By allowing students to perform iterative data collection with direct instruction on analysis and data interpretation lead to improved capabilities amongst undergraduate students to interpret and analyze data (Brownell et al., 2015). The findings of this study and across the literature demonstrate that inclusion in authentic practices in introductory courses is beneficial for developing *Science as Process* skills across a larger population of students.

Science as Sociopolitical Factor:

Science is steeped with social and political factors that impact and influence how science is both conducted and consumed by individuals. According to Hand and colleagues (2003), reading and writing literacies are constrained by sociocultural impacts. In order to develop science literacy through writing, a student must understand their community and both understand and reconcile their epistemological beliefs. Sociopolitical topics often encompass personal or lived experiences that may influence a student's views (Barzalai, Tzadok, & Eshet-Alkalai, 2015). For example, in an attempt to understand how students source information about a sociopolitical topic they had direct experience with, Barzalai & colleagues (2015) found that students did little sourcing of primary research when constructing arguments, but instead relied on their own socially constructed views. However, when students more extensively researched the topic and relied less on their own views, they were able to construct more elaborate complex scientific arguments. Furthermore, "individuals' attitudes and moral convictions…influence how science-related information is processed cognitively and emotionally" (Sinatra, Keinhues, & Hofer, 2014, p. 124).

Apart from being able to understand that there are social, political, and moral implications of science, students must also recognize this when they think about the broader implications of their experiments. For example, in order to understand the broader significance of the experiment, traditionally discussed in the introduction and discussion sections of a manuscript, students must recognize that their science not only has direct impacts in the field but often science is charged with understanding problems that often time has global impacts (Hurd, 1975). This can often prove to be a daunting task, as it requires students to access scientific information and then integrate that scientific information with a societal issue (Cavgnato, 2010). The *Science as a Sociopolitical Factor* domain of the conceptual framework can evidence this integration of scientific knowledge and its corresponding societal influence. By engaging in authentic practices, students conform to disciplinary norms in which they are prompted to think about these broader issues when compared to traditional “cookbook” or expository laboratories (Domin, 1999).

By exposing students to authentic processes, explicitly writing, they not only develop skills that help them to identify areas in which science is socially influenced but also, identify how they could use science in order to form judgments, make life and social decisions, and use science to act (Grooms et al. 2014). Identifying a sociopolitical link in science is a skill that is both underdeveloped and a critical to science literacy. With the development of technology, access to science information is more widespread, and students are interacting with science daily (Sinatra et al., 2014). Additionally, students need a foundational understanding of how politics, economics, and social practices impact science in order to make informed decisions regarding scientific processes within a democratic society (Feinstein, 2015). Within authentic manuscript writing, we can see these connections in two distinct places, in the introduction and the discussion sections. Furthermore, there are integral connections between the *Science as a Sociopolitical Factor* and both the *Science as Process* domains, in terms of how sociopolitical contexts and/or constraints can affect certain methodologies, and the direct connection to *Science as Access* domain in terms of using the scientific literature to argue the sociopolitical topic.

Exposing students to authentic practices in large-enrollment introductory courses, as well as introducing students to sociopolitical topics, leads to more students engaging authentically with science. This, in turn, will help to develop the skill of identifying a sociopolitical link to science and thus, understand different impacts on science and science research; researchers agree that to achieve more scientifically literate students, we need to support this in the way that we teach science courses to our undergraduate students (Brown et al., 2005; Brownell et al., 2013).

In conclusion, the prior research discussed in this chapter points out that science literacy is a complex construct that is often difficult to define and is defined differently among researchers. This prior research also shows that more work is needed in order to understand this construct more fully, especially at the undergraduate level. In an attempt to consolidate, define, and understand this construct, I have developed a conceptual framework (Figure 2.1) that composes three domains, *Science as Access*, *Science as Process*, and *Science as a Sociopolitical Factor*. Each domain comprises authentic practices in the field of science; for example, reading and assessing literature, completing and analyzing experiments, and understanding the broader implications of science in society. If we hope to develop science literacy in students, the logical deduction as demonstrated by this body of literature would be to expose them to authentic practices in the classroom. While there have been curricular changes to do just that, one of the most authentic practices that is often eliminated in science courses is meaningful, authentic writing (Holyoak, 1998). This is often attributed to a lack of disciplinary discourse among students; however, in order to develop a discursive identity, one must be immersed in the community of practice; one such practice being authentic writing. Authentic writing practices, particularly manuscript-style writing, incorporate all three domains of science literacy and allows introductory students to engage in disciplinary community practice, while also allowing for iteration of this practice, a hallmark of authentic practice.

Summary:

Chapter two of this dissertation has consolidate current literature on science literacy and provided a new conceptual framework on how to define science literacy and apply it to authentic disciplinary practices such as manuscript-style writing assignments. The literature review also applied the conceptual framework for science literacy to authentic disciplinary practices in science as they aligned with the specific domains that align with science literacy. I discussed how students who engage in authentic disciplinary practices can start to develop science literacy as early on in their academic career as their large-enrollment introductory STEM classes. Chapter three will provide the background and foundation for the methodological and analytical approach used to address the following research questions:

1. How do students demonstrate science literacy at different points in the writing process as they work towards completing a manuscript-style writing assignment?

2. How do course artifacts (drafts and rubric) related to this assignment demonstrate science literacy?
3. How do students talk about what it means to be scientifically literate?

Chapter 3: Methodology

In order to answer the research questions of my dissertation study, I examined undergraduate students' manuscript-style writing in an introductory lab-based biology course intended for STEM majors. It involves examining aspects of science literacy that are demonstrated in data from multiple points in the authentic writing process including: the rough and final draft of the manuscript, the peer review process, and reflections that each participant completed. In this chapter, I provide detailed information of my study design, including descriptions of the study context, research procedures, and methods of analysis.

Purpose

While research has demonstrated that authentic practices improve science literacy, engages students in the community of practice, and describes writing as an authentic practice, little research focuses on authentic writing practices at the introductory undergraduate level in laboratory STEM courses. Therefore, the purpose of this study was to explore aspects of science literacy that emerge when introductory undergraduate STEM students engage in authentic writing practices. Three research questions informed the study design:

1. How do students demonstrate science literacy at different points in the writing process as they work towards completing a manuscript-style writing assignment?
2. How do course artifacts (drafts and rubric) related to this assignment demonstrate science literacy?
3. How do students talk about what it means to be scientifically literate?

In answering these questions, I explored the ways in which different aspects of science literacy are demonstrated at different points in the writing process, in course artifacts, and in students' talk both about their writing process and about what it means to be scientifically literate. By exploring different points in undergraduates' writing process as they engaged in manuscript-style writing assignment, I was able to identify indicators of science literacy that are present in the students' existing schema of science literacy and identify patterns in these indicators that might demonstrate science literacy across the three domains proposed in the conceptual framework described in chapter two of this dissertation study. Examining course artifacts provided me insight into the ways in which the guidelines set forth in the rubric for the manuscript style writing assignment supports (or hinders) aspects of science literacy. And finally, exploring how students discuss what it means to be scientifically literate provided me insight into students' understanding of this concept. This was the focus of my dissertation research. In the sections that follow, I provide further detail on the full study design.

Rationale for Study Design:

Authentic Artifacts as Data Sources

In order to develop a rich understanding of how introductory STEM students were demonstrating science literacy multiple artifacts from the writing process, including reflections, written drafts, and the rubric were collected along with multiple interviews (Figure 3.1).

Data for this dissertation involved eight sources all connected to the plant nutrition module assignment described below: (1) a pre-interview (2) the written rough draft, (3) a written reflection of the draft writing process, (4) a think-aloud interview on the revision process, (5) a written reflection on how the revision process aided/didn't aid in the overall revision of the manuscript, (6) a written final draft of the manuscript, (7) the stimulated recall interview and, (8) the rubric. Figure 3.1 illustrates the order in which each data source was collected as well as provides a brief description of the activity each data source involved. These seven data sources and how they were collected are described next.

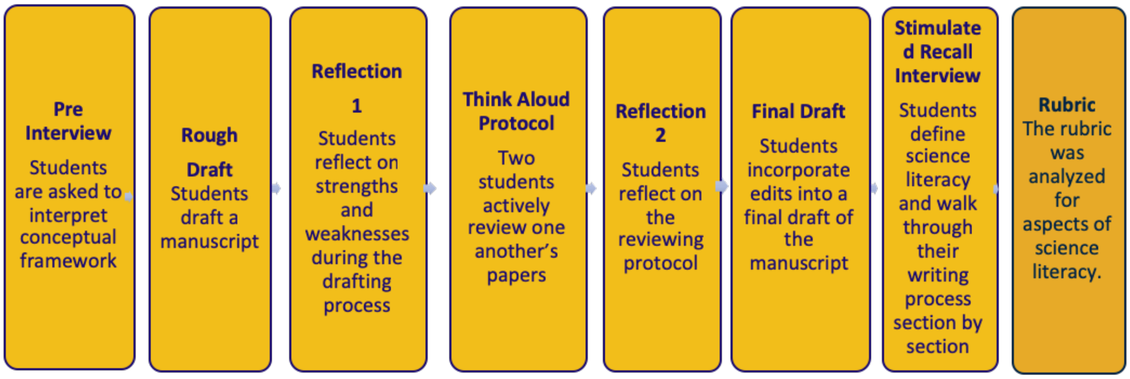

Figure 3.1: Data Sources. The artifacts were collected over a two-week period aligned with the course time line. The rough draft and the final draft were assigned during the course for credit.

Pre-Structured Case Studies

The research methodology employed in this study involved the use of pre-structured case studies. Pre-Structured Case Studies can be used in research when the researcher has developed a clear conceptual framework (Miles, 1990; Miles, Huberman, and Saldana, 2014) from which to examine case-related data. Using a pre-structured case design allows for management of data and straightforward data analysis. Miles (1990) posits that although pre-structured case studies provide for a straightforward analysis, it still maintains rigor and a systematic approach to meaning making. In this study, I use the three dimensions of the conceptual framework that I have posited as the basis for analysis and meaning making of my data.

The pre-structured case study approach often utilizes interviews as the primary methodological tool. Document analysis is also an acceptable data source for this approach (Miles, 1990). For presenting the results of a pre-structured case, an outline of how those results are going to be presented are determined. Furthermore, the pre-structured case is presented so that there is direct data accompanied by analytic text within the written analysis section (Miles, 1990). This approach also allows for cross-case analysis.

In the case of this research, the results will be presented in the following manner for each individual participant: (1) how the student defines science literacy and how it is perceived to be shown in one's writing; (2) how aspects of the Science as Access domain of science literacy emerge through the manuscript-style writing process; (3) how aspects of the Science as Process domain of science literacy emerge through the manuscript-style writing process; and, (4) how aspects of the Science as a Sociopolitical Factor domain of science literacy emerge through the manuscript-style writing process. In addition, after presenting each individual case, interesting trends that have emerged will be discussed. Furthermore, the pre-structured case is presented so that there is direct data accompanied by analytic text within the written analysis section (Miles, 1990). This approach also allows for cross-case analysis.

Research Perspective

The research perspective that grounds this study is constructivism (Crotty, 1998). Constructivism suggests that learning is "the meaning making activity of the individual mind" (Crotty, 1998, p. 58). Furthermore, constructivism allows the researcher to consider the unique experience of the individual. In this study, being able to understand the experience of the individual is critical to understanding how they are making meaning of the authentic writing process and how aspects of science literacy emerge, or become apparent, during this meaning making process.

More specifically, this perspective allows me to see how each participant is making meaning of their writing process and to see which aspects of science literacy emerge as they are making sense of how to write manuscript-style laboratory reports. Constructivism posits that students are not blank slates but rather bring with them prior knowledge used in the construction of new knowledge. This research perspective aligns with this research in that students have prior knowledge of scientific writing from their pre-requisite course instruction, and it is assumed that students use this knowledge to build new knowledge of scientific writing specifically and science literacy more broadly. This study will explore which aspects of science literacy are evident at various points in students' writing process given the understanding that they have had prior instruction in this process.

Study Design

University Description

This research was conducted in an undergraduate biology program context at a Land-Grant institution in Appalachia. In 2017, the university served a total of 22,504 undergraduate students enrolled full time at the university. A total of 8,936 students were enrolled in STEM majors. For the specific college that houses the biology major, there was a total of 4,942 students enrolled, 707 of those students listed as biology majors. Of the 707 enrolled 408 were female and 299 were male. Ethnically, the demographics were 563 Caucasian students, 30 African American students, 18 Latinx students, 39 Asian students, 2 American Indian students, 2 Native Hawaiian/Pacific Islander, 36 who identified as 2 or more races, and 17 students who did not identify their ethnicity.

Program Context: Core Biology Major Curriculum

The undergraduate biology major core curriculum includes a sequence of five courses: BIOL 115, BIOL 117, BIOL 219, BIOL 221, and BIOL 320/321 (Capstone). These courses are all SpeakWrite certified. SpeakWrite certified courses implement disciplinary specific writing and communication practices; students who complete SpeakWrite certified degrees, such as biology, should be able to apply content knowledge, analyze information, and communicate in multiple contexts.

In addition, manuscript-style lab reports are required in all of these courses except BIOL 221, which does not have a laboratory component. Manuscript-style laboratory reports include written sections resembling what is typical in the field of biology (and other STEM disciplines). These sections include: an introduction (including in text citations and argument construction), a description of one's methods, a presentation of one's results (including statistical analyses), and a discussion of the results (including in text citations and argument construction). Table 3.1 provides an overview of this course sequence. Each course in the core curriculum is briefly described next.

Table 3.1: Description of five-course Biology Sequence (italicized course is the course context for this dissertation research).

Semester	Course	Material Covered
FA Year 1	BIOL 115: Introduction to Biology	Introduction to the cell and cellular processes (photosynthesis, cellular respiration, glycolysis) DNA/RNA properties and replication, Central dogma Mendelian genetics; gene expression, introduction to natural selection
SP Year 1		*Taxonomic categorization; diversity of species, phylogenetics and properties,*

	BIOL 117: Introduction to Physiology	*plant structure, plant nutrition and processes, Human physiology (nervous, endocrine, respiratory, circulation, and digestion systems)*
FA Year 2	BIOL 219: The Living Cell	More in-depth description of the cell, amino-acid chemistry, detailed gene expression, cell transport, DNA replication, repair, and properties, RNA. Transcription and Translation etc.
SP Year 2	BIOL 221: Ecology and Evolution	Provides instruction on evolution and ecology including topics such as Darwin's theory, population genetics, population growth and regulation, human ecology etc.
Variable Semester	BIOL 320/321: The Total Science Experience	This course serves as the capstone for the biology curriculum. Students engage in authentic research including proposal writing, experimental design, data collection, analysis, manuscript writing, and public presentation of data.

BIOL 115 Introductory Biology, is the first course in the biology major core curriculum. This class is composed mainly of first year students in STEM majors. This class introduces the cell, macromolecules, and cellular processes (photosynthesis, cellular respiration, glycolysis, etc.), DNA/RNA properties and replication, the central dogma of biology, Mendelian genetics, gene expression, and introduction to natural selection. The laboratory component focuses on developing particular aspects of scientific writing in a piecemeal fashion, including hypothesis construction and development, carrying out experiments and data collection, simple data analysis (standard curves and simple statistics, such as means), graphing, locating primary literature and developing basic scientific arguments. This instruction is in addition to teaching basic lab skills like dilutions, pipetting, spectrophotometry, transformations, and general lab safety.

BIOL 117 Introduction to Physiology, is the second course in the biology major core curriculum. This class is composed primary of first year students in STEM majors. This class introduces topics such as taxonomic categorization, diversity of species, phylogenetics and properties, plant structure, plant nutrition and processes such as reproduction and hormone production, and provides and introduction to human physiological processes. The laboratory component further develops the skills that were previously taught in the BIOL 115 lab. Instruction around components of scientific writing is reiterated in the curriculum to ensure consistency of instruction. In order to develop students' scientific writing further, this course requires students to write two full manuscript-style laboratory reports (BIOL 115 requires just one such writing assignment). Students are also introduced to more complex statistical analyses such as student t-tests, and are introduced to larger data sets (individual groups to whole class). This instruction is in addition to basic lab skills such pipetting, pigment isolation, microscopy, gel electrophoresis, and protein isolation.

BIOL 219 The Living Cell, is the third course in the biology major core curriculum. This course has a pre-requisite of BIOL 117 and CHEM 115 Fundamentals of Chemistry. The curriculum in BIOL 219 delves deeper into the molecular processes of the cell. This course further develops an understanding of macromolecules and cellular processes. It also focuses on amino acid chemistry, more detailed gene expression, cell transport, in depth coverage of DNA/RNA properties, DNA replication, repair, modifications, and transcription and translation. In the companion lab, there again is a focus on developing scientific writing skills, this time modifying the basic writing to adapt to a cellular biology format of scientific writing. This specialization adds to the overall writing skills that the students have focused on in BIOL 115 and BIOL 117. BIOL 219 also requires students to write two full manuscript style laboratory reports in a cell biology format. In addition, students are introduced to technical writing in the field for their required third writing assignment. The technical report provides an opportunity for students who wish to go into industry after their undergraduate studies a space to receive instruction on how to write experimental results in a technical fashion. In addition, the BIOL 219 lab focuses on teaching scientific skills such as, DNA isolation, purification, and quantification, gel electrophoresis, polymerase chain reaction (PCR), Sanger sequencing, microscopy, pipetting, and bioinformatics.

BIOL 221 Ecology and Evolution is the fourth course in the biology curriculum. It is a lecture-based course where students are introduced to topics including Darwin's theory of evolution, population genetics, population growth and regulation, speciation, and human ecology. This course does not have a laboratory component. BIOL 320/321 The Total Science Experience, serves as the capstone course. The main difference between BIOL 320 and 321 is the topics of material. BIOL 320 is the genomics focused capstone versus BIOL 321 which is an ecology-based capstone. Students only have to complete 1 capstone class. The capstone is the most authentic course-based research experience that the students take part in. The students are expected to work as a group to complete the following assignments: (1) a written proposal, (2) an experimental design, (3) carry out the proposed experiment, (4) collect and analyze data, (5) complete a manuscript-style laboratory report, and (6) present their research in a public forum, student present either a formal presentation or a poster at a departmental poster session.

Participants:

In order to recruit participants for this study, all student enrolled in BIOL 117 during the Summer of 2017 term were given the opportunity to complete a pre-study survey which elicited information about undergraduate major, sex, final grade in BIOL 115 (a pre-requisite for BIOL 117), their final grade in English 101 (if completed), and other information about their science background, and who influenced them the most regarding science topics. The sampling technique that was used was both purposive and a convenience sample (Miles, Huberman, & Saldana, 2014). It was a convenient sample because I, as a graduate teaching assistant in biology, had access to students enrolled in the course. It was purposive because the research attempted to explore aspects of science literacy in an introductory laboratory course. Exclusion criteria for this study were: not reporting their BIOL 115 final grade (or equivalent) and if they were not enrolled in BIOL 117. Since the study was exploratory in nature, its purpose was not to generalize its findings, but rather to gain insight into the range of ways students demonstrate science literacy in their writing in an introductory laboratory course. Therefore, this sampling procedure was purposefully employed in order to obtain a diverse range of students who were enrolled in BIOL 117. Recruiting participants in terms of STEM majors represented (Table 3.2). Students who volunteered to participate in the study were to receive a fifty-dollar Amazon gift card at the completion of the study.

Eight undergraduate students who were enrolled in Biology 117: Introduction to Physiology Laboratory in the summer of 2017 served as participants in this study. Students were also enrolled in the lecture component of this course. Participants were recruited from the BIOL 117 lecture, and the opportunity to participate was open to all of the students enrolled in the course, there were a total of 45 students enrolled in BIOL 117 during the Summer of 2017. The study was described to all student, who were also told that they would receive a fifty-dollar Amazon gift card at completion of the study for their participation. All participants identified as STEM majors including: Biology (3), Pre-pharmacy (1), Psychology (1), Chemistry (2), and Medical Microbiology (1). Participants' ages ranged from 18-22 years of age. All participants had previously completed at least one other undergraduate biology course; six participants took the BIOL 117 pre-requisite BIOL 115 and all of them received an A. One participant took the BIOL 115 equivalent, BIOL 101 and BIOL 102 and received an A in both courses. One participant took a BIOL 115 equivalent at a different university and earned a C+. All participants were assigned a pseudonym. Table 3.2 provides an overview of the eight participants' prior course experience and majors.

Table 3.2: Overview of Participants' Prior course experiences and majors.

Participant	Major	BIOL 115	BIOL 115 Grade	ENGL 101	ENGL 101 Grade
Anna	Biology	No (BIOL 101-104 Sequence)	N/A (A in all 4 courses)	Yes	A
Tim	Biology	Yes	A	Yes	A
Stacey	Immunology and Medical Microbiology	Yes	A	Yes	A
Sean	Biology	Yes	A	Yes	Not Reported
Jen	Pre-Pharmacy	Yes	A	Yes	A
Joey	Chemistry	Yes	A	Yes	B
David	Psychology/Chemistry	Yes - Equivalent	C+	No	N/A
Christie	Psychology	Yes	A	Yes	A

I describe each individual participant next. The information in these individual descriptions was gathered prior to the start of the study through both a pre-study survey and a pre-study screening interview.

Anna: Anna reported being a biology major. Anna was a second-degree seeking student, she previously completed a B.A. in English. Prior to enrolling in this summer section of BIOL 117, Anna completed the alternative biology track intended for non-STEM majors, BIOL 101,102, 103, and 104 where she earned an A in all four courses. The course work for the BIOL 101, 102, 103, and 104 sequence is considered to be equivalent to BIOL 115. One difference is important to note, however; this sequence did not require manuscript-style lab reports, so Anna had no previous scientific writing experience outside of BIOL 117. Anna had also completed ENGL 101 with a grade of an A. When asked, Anna described her science background as having no science background, even though she took a year of college level biology. She also described having a strong background in writing; however, she recognized that she did not have any background in the writing conventions of science. Further, when describing what has influenced the way she learns in science courses, Anna she claimed to be most influenced by her English degree. She also described that her experiences in other classes have shaped and taught her how to learn.

Tim. Tim reported an intention to major in biology. During his screening survey, Tim mentioned that he had an extensive science background evidenced by the high number of STEM courses that he took in secondary school. Tim gauged himself as having adequate skills in writing in science. He described being confident in his ability to write, and he claimed to have adequate science content knowledge, while also suggesting that even though he was adequate, there was always room for improvement. Tim also described himself as a driven individual and a self-motivated learner who is determined to be successful. During the interviewing process, Tim mentioned that he was previously an engineering major. Tim was successful in both the pre-requisite for BIOL 117 and his ENGL 101 courses having earned an A in both courses.

Stacey. Stacey reported being an Immunology and Medical Microbiology major. Prior to enrolling in this summer section of BIOL 117, she successfully completed BIOL 115 having earned an A. In addition to completing BIOL 115, Stacey took ENGL 101 as dual credit in high school where she had also earned an A. Stacey described her background in science as good; however, she also described her ability to write in science as moderate. She identified a high school teacher as the person who had taught and influenced her the most in her science learning as well as being the person who taught her how to write in science. Stacey attributed her everyday experiences with science in her out of school experiences that had shaped her overall learning.

Sean. Sean reported being a biology major. During the screening survey, Sean claimed that he had a very deep understanding of biology coming into Biology 117. Prior to enrolling in this course, he also successfully completed Biology 115 having earned an A. Sean attributed his background in science and his learning of science to his father. Sean explained that is father was a science teacher. Sean also mentioned that experiential learning with the Boy Scouts have shaped the way that he learns in the sciences. When asked how confident he was regarding his ability to write, he said he was relatively confident in his abilities. Sean had completed ENGL 101 prior to enrolling at the university.

Jen. Jen reported an intention to major in pre-pharmacy. During the screening survey, Jen stated that she had a fair background in science. In addition, she also claimed that she was a decent scientific writer. Jen also stated that her professors and the way that they engage with the material while teaching have most impacted her learning in science. Jen was successful in both the pre-requisite for BIOL 117 and in her ENGL 101 courses having earned an A in both courses.

Joey. Joey reported being a Chemistry major. Prior to enrolling in this summer section of BIOL 117, Joey had successfully completed BIOL 115 having earned an A. Joey had also completed ENGL 101 having earned a B. Joey described having a good chemistry-based background with some foundation of biology. Joey also described having a good level of confidence in his ability to write in a scientific manner specifically when writing lab reports. He described his love of sciences as the most influential factor in how he learns science and identified this as self-motivated. Joey did not attribute a single out of school experience as one that had shaped how he learns in science; however, he did describe that he learns through trial and error and this has shaped how he learns in science.

David. David reported being a Psychology and Chemistry double major. Prior to enrolling in this summer section of BIOL 117, David successfully completed BIOL 115 having earned a C+. David described his background in science as good in chemistry and physics, but overall lacking in the biological sciences. Although David had not taken ENGL 101 at the time of this study, he described his ability to write in science as high. David attributed his interest and learning in science as being most influenced by his chemistry professor. David described his professor as both motivating and as a person who gave him opportunities that helped him be successful. David also described that prior out of school research experiences that taught writing, comprehension, and experimentation as out of school opportunities that have best shaped how he learns in the sciences.

Christie. Christie reported being a Psychology major. During her screening interview, Christie described her science background as moderate; however, when asked to describe her confidence in her ability to write about science, she described her ability as fair. Christie stated that her boyfriend has influenced her the most when it has come to learning about science. She described that she learns science through her experiences with him in trying to explain mechanical and biological mechanisms; she further described that they enjoy challenging one another to figure out how things work when they do not understand. Additionally, when asked what out-of-school experiences have shaped how she best learns science, Christie described observation and experiential learning. For example, she described learning about science by observing different organisms during a hike, or by understanding how her own body works. Christie was very successful in both the pre-requisite Biology 117 and in her English 101 course having earned A's in both.

Pertaining to all eight participants, certain assumptions were made about participants' prior knowledge, skills, and experiences in laboratory-based science courses. Prior to the beginning of BIOL 117, students were assumed to have a general working knowledge of the science process in the lab setting. Students were expected to be able to formulate hypotheses, follow laboratory protocols, analyze and interpret data, and draw conclusions based on data as these process skills were explicitly taught in BIOL 115. In addition, students were expected to have a basic working knowledge of scientific concepts developed in the first course of the three-course sequence (Table 2). These concepts include understanding the scientific method, photosynthesis, the central dogma of biology (transcription/translation), genetics, and a brief introduction to community, and population ecology. In addition, students enrolled in the BIOL 117 laboratory were assumed to have a basic working knowledge of the scientific writing process and to have received instruction on how to write each section of a manuscript of a scientific study specifically in their previous pre-requisite course. Prior to the study, a review on how to write each section of a manuscript was provided in BIOL 117. Therefore, students who participated in this study have had explicit prior instruction in writing in science and thus it is assumed they have prior knowledge of writing in science to draw on when engaging in the various authentic writing practices involved in this dissertation research.

BIOL 117 Writing Assignment Context

The eight participants were recruited from a summer section of Biology 117: Introduction to Physiology at a land-grant institution in the Mid-Atlantic region of the United States. This course included a laboratory section in which disciplinary specific instruction in Biology, including rhetoric and conventions were briefly reviewed in the course. An overview of the course topics and writing tasks are outlined in Appendix F. As part of this course, students worked in small groups consisting of 2-4 students and discussed the process and product of writing the different sections of a manuscript-style laboratory report, (e.g. the structure of an introduction and the logical topics that should be included in each section). Also, as a part of this course, students experienced and discussed each section of a laboratory manuscript-style writing assignment (e.g. introduction, methods, results and discussion) prior to the writing assignment pertaining to this research project. In addition, students completed guided library searches in order to support skill around finding relevant literature of the biology concept being investigated in the lab setting. Therefore, I expected that the course context and various assignments and activities served as a means to support the students' cognitive skills of the writing process in science and thus, I assumed the writing assignment related data from this context could provide insight into two of the domains of science literacy that I identified in my conceptualization of this construct: *Science as Access and Science as Process* (see Figure 2.1 in previous chapter). Further, the specific assignment context for this dissertation study involved biology content connected to agriculture, which I expected would provide insight into the third domain of science literacy, *Science as a Sociopolitical Factor.* I discuss this specific writing assignment next.

The writing assignment used in this study was introduced in the third week of the six-week course and was considered to be the laboratory summative assignment for the plant nutrition module. Each component of the assignment was described in detail to the students and an evaluation rubric was provided. These components aligned with an inquiry-based curriculum (Weaver, Russell, & Wink, 2008) module on plant nutrition and required students to generate research questions, form hypotheses, develop the experimental design, including defining variables, and carry out their experiment. More specifically, this plant nutrition module started by having small groups of students write a mini grant-style proposal designing a study where they explored one macronutrient required for proper plant growth and development. This small groups writing assignment required the students to frame the significance (or broader context) for studying their particular nutrient. Later, when students were required to individually write the results of their experiment in a manuscript-style writing assignment, each student also had to frame the significance (or broader context) for the experiment. I therefore expected that data from this plant nutrition context could provide insight into the *Science as a Sociopolitical Factor* domain of my proposed science literacy model as plant nutrition has ties to agriculture and farming, both issues of concern in Appalachia (Farmer & Betz, 2016; Dobson, Perrett, Samson, & Malone, 2016).

After the small groups completed their proposals, each group presented its proposal to the whole class, which then voted on the best-designed experiment. In determining which proposal represented the best designed experiment, students had to consider the presented significance of the study, the overall argument for the study presented by the group, the feasibility of completing the experiment in the scope of time allocated, and the completeness of the methods for carrying out the study. Once the class agreed on the best experimental design, critical methodological components missing from the proposal were discussed and modifications to the experimental design were made. The whole class then solidified the methodological design of the study including identifying null and alternative hypotheses that would later be used when analyzing data generated from carrying out the plant nutrition experiment. From there, all students conducted the winning proposed (and further modified) experiment. Upon completion of the data collection, the students analyzed and graphed their data using the appropriate graph type and simple statistics (i.e. means, standard deviations, standard error, and two tailed student t-tests). I therefore expected that data from this plant nutrition experiment to provide further insight into the *Science as a Process* domain of my proposed science literacy model.

Finally, after students completed the analysis portion of the plant nutrition experiment, they were required to complete a summative written assignment of this module. This was an individual assignment where students reported the results of the plant nutrition experiment in the form of an authentic manuscript style writing assignment. Components of this manuscript included an introduction, methods, results, discussion, and literature cited section. Students were expected to refer to and cite appropriate literature that both framed the significance of the experiment as well as its broader impacts. A detailed evaluation rubric was provided to communicate clear expectations for each section of the manuscript and to guide students' writing (Appendix G). This summative assignment required students to submit a rough draft for instructor feedback. In class, a peer review of the rough draft was also completed. The rough draft was scored according to the rubric, and scores were adjusted by 20% to indicate the rough draft grade earned. The score was adjusted to allow the draft to be a low stakes formative assignment, the same standards for the final paper were presented and utilized the same rubric for consistency. For the peer review, pairs of students exchanged rough drafts, while using the rubric as a guide, they engaged in a thorough read of each section of their peer's rough draft, noting feedback along the way. The peer review process took about 45-minutes to an hour of class time.

It is important to note that the laboratory summative assignment and related course activities described here are requirements expected of all students enrolled in this course, whether they chose to participate in this dissertation study or not. I did not serve as the Graduate Teaching Assistant for this course; therefore, I was not responsible for any grading associated with the assignment. Assignments were graded according to the expectations and criteria set forth in the course syllabus and provided rubrics. In addition to these course requirements, students who chose to participate in this study were asked to complete a pre-interview (Appendix B), two additional written reflections on the writing process (one completed after the rough draft and one completed after the revision process), a think-aloud interview about their revision process (completed as a peer review separate from their peer-review completed in class), and a stimulated recall interview to discuss the overall writing process associated with the summative written assignment described here. The peer review completed during the think-aloud interview was in addition to the peer review that was completed in class. These additional expectations were described to the participants during the recruitment process and did not affect students' course grades. Furthermore, the summative assignment grades were not impacted by participation in the study.

Description of Data Sources and Data Collection:

Written Assignments. Two of the data sources stemmed from the plant nutrition module assignments described in the previous section: the rough draft of the manuscript and the final draft. Participants completed these writing assignments using Google Docs. I gained consent from study participants to access their written work (all drafts and products) through Google Docs. Other researchers have examined the use of Google Docs in a collaborative writing assignment setting (Zhou, Simpson, & Domizi, 2012). These researchers found that using the Google Doc did not impact their overall performance on their writing assignments; but, did allow students to collaboratively work on writing assignments (Zhou, Simpson, & Domizi, 2012). Therefore, I utilized this technology in order to gain insight into participants' writing process and how they actively constructed their arguments about the plant nutrition study. By using Google Docs, I was able to track changes students made as they crafted their manuscripts. This allowed me to see aspects of science literacy as students engaged in the writing process (as opposed to only seeing those aspects evident in the final assignments they submitted). Each participants' Google Doc generated rough draft and final draft of the plant nutrition manuscript were downloaded as a word document at the due date to view aspects of science literacy demonstrated until that point. This was done a total of two times (submission of rough draft and the final submission).

Reflections. Participants were asked to write a reflection two times on their writing (once on the rough draft, and once after the revision process) in order to gain further insight into their overall writing process. These written reflections provided an overarching question and were open-ended to allow the students to reflect on their individual writing process (Appendix C). These reflections were intended to allow the students to actively think about their writing process and self-identify where there were gaps in their knowledge or challenges that they had in their writing. Other researchers have shown that providing opportunity for students to reflect on the writing process can promote self-regulation of the writing process (Boskar, 2016; Bowman et al., 2016, Hayes, 1987). Reflections have also been demonstrated to promote deeper contextual understanding of content (White & Frederiksen, 1998; Lee & Butler-Songer, 2002). For this research, these written reflections were collected and analyzed according to the three domains in order to gain further insight into the participants' writing process.

The first written reflection took place after the first full draft of the summative assignment prior to the peer review and revision process. For the first written reflection, students were asked to reflect on each section of drafting their rough draft of the manuscript. More specifically, they were asked to describe any trouble spots they encountered when writing the draft or limitations they faced in the writing process of each section; likewise, they were asked to reflect on where they felt strong in the writing process. The second reflection took place after the think-aloud interview/reviewing process. Students were asked to reflect on the revision process and how it aided/did not aid the writing process. More specifically, students were asked to identify areas of uncertainty and if they understood all of the changes that were suggested to be made.

Think-Aloud Interview. A think aloud protocol was used to gain access into how the participants revised their papers and provided feedback to their peers. This interview was structured similar to a peer review; however, students were asked to think-aloud while they conducted the peer review. A think-aloud interview is a method that allows insight into underlying cognitive processes by having participants think out loud while performing a task (vanSomeren, Barnard, & Sandberg, 1994). More specifically, I argue that the think-aloud protocol could be used to gain insight into the elements of science literacy that would otherwise remain hidden by only looking at the written artifacts. The think-aloud protocol has previously been used in research to engage students in the authentic practice of peer review (Graff, 2009).

To prepare participants for this non-traditional interview structure, I asked students to think aloud as they counted the number of windows in their house. This approach was used to acclimate students to think aloud as they count, a task normally completed silently. Another training method that was used was to solve a simple algebra problem while thinking out loud. These processes introduced them to thinking aloud, a process that does not naturally occur (Anders Ericsson & Simon, 1998).

After the participants practiced the think aloud structure through these tasks, I conducted a think-aloud interview around their revision process of the rough draft. The think aloud protocol asked the students to think out loud as they revised their partner's rough draft. This allowed me to gain insight on how the students revised their work and ultimately addressing the feedback and how they chose to/or not incorporate it into their writing. If the student was able to correct the feedback provided by the reviewer, this suggested that they had the working knowledge to address the cognitive dissonance; this would suggest that the students were able to address the missing components of the manuscript-style writing. This parallels with science literacy as a scientific literate person may not have perfect drafts but they do have the ability to correct and edit that draft.

Students were asked to work in pairs to revise their manuscripts during the think aloud interview. This pairing is intentional given that I assumed a constructivist epistemology (Crotty, 1998)-that is, knowledge is co-constructed- and the revision process is typically not completed in isolation. The overall think-aloud interview ranged from 40 minutes-2 hours to complete dependent upon the pair of students. Six of the eight participants worked in pairs completing this think-aloud interview. Both students focused on revising one paper at a time, one as the reviewer and one as the reviewee; the students then changed roles to complete the think-aloud on the other paper. Two students were interviewed alone and conducted a think-aloud of their own papers due to the fact that two participants dropped out of the study.

As, the researcher, I acted as an observer as the process occurred and I interjected with a question about why they were doing a certain revision whenever I noticed they were not thinking aloud through the revision process. My interjections were only meant to stimulate their thinking aloud, not to direct their revision process; however, there were circumstances where I interjected to address severe dissonance that I did not believe that the other participant could address. For example, one participant discussed fitting curves to data, this is not something that was taught in the class but was incorrect about the interpretation of the data.

The participants were given a list of questions at the beginning of the think-aloud protocol to prepare them; I used the questions as a tool rather than a script to be followed (Appendix D). The think-aloud protocol tool mimicked the structure of the stimulated-recall interview protocol (described next) in order to draw parallels in the writing process. During the think aloud, I asked the author of the paper probing questions such as *"What are you missing? "*or *"Why did you analyze the data in that manner?"* to gain insight into whether or not the student actually understood why the change was being suggested. During the think-aloud, for the students who worked in pairs, I asked that the team member working on the revision allowed the author to respond to probing questions while the other student listened to the responses. Then the peer provided feedback and made suggestions to the author of the manuscript. Upon completion of the first person's think-aloud protocol the participants switched roles and focused on the other student's manuscript. Students were asked to reflect on the overall revision process and the think aloud as previously described above.

Stimulated-Recall Interview. A stimulated-recall interview was conducted in order to gain access into how students demonstrated their science literacy through the writing process. Stimulated-recall interviews allow researchers to study cognitive processes; it is an introspective approach that asks participants to reflect on their process (Lyle, 2003)-specifically in this case, the process of manuscript writing in science. Airey & Linder (2009) used a stimulated-recall interview with undergraduate physics students to gain further insight into their learning from lectures. In a similar way, this interview method was used in this dissertation research in order to understand how the students demonstrated science literacy through writing in science. The summative assignment previously described served as an artifact in the stimulated recall, which allowed insights surrounding all three aspects of the participants' science literacy, *Science as Access* (how they described their content knowledge and literature search), *Science as Process* (how they described the methods used in the experiment, data collection, and data analysis), and *Science as a Sociopolitical Factor* (how they described the significance of the study to a broader context). Specifically, the participants were asked questions (Appendix E) in order to understand these three aspects of their science literacy. In addition, students were also asked to define science literacy (in their own terms) during the stimulated recall interview and asked how science literacy is demonstrated in their writing after completing the interview. In addition to the stimulated recall interview, the summative assignment was analyzed to corroborate the writing process participants described in the interview.

The Rubric. The rubric associated with the manuscript-style writing assignment was also used as an artifact in the study. It was coded to determine what aspects of science literacy were built into the rubric. The rubric was then used to assess both the rough and final draft of the participant's manuscript, thus assessing the components of science literacy within the actual writing artifacts.

Data Analysis

The analysis for this study was informed based on my pilot study results. Codes that emerged from the pilot study were used to guide the analytical approach. A code table can be found in the appendix (Appendix H). The pilot study results suggested that there were four main themes that emerged: (1) Students enter into the field literature and have to reconcile and restructure knowledge; (2) Students gauge credibility through what they think is important; (3) Students make meaning/understanding of their own research, which includes understanding research of others; (4) Students write for conventions and not for science literacy. The first three themes supported the *Science as Access* component of the science literacy model and the fourth theme supported *Science as a Process* component of science literacy.

Prior to coding data, both the think-aloud and the stimulated recall interviews were transcribed to include all aspects of vernacular including, pauses, um, ahh, and any other utterances provided by the participant in order to capture the full tone of the interview. The interviews were transcribed using the computer software ExpressScribe (NCH, 2017). The data (both the interview transcripts and summative assignment artifacts) was coded both deductively, using codes driven by the conceptual framework that were developed during the pilot study (Table 3.3) and inductively with a coding scheme developed from the data rather than from pre-determined codes (Kvale & Brinkman, 2009) thus allowing the data to build the theory around what aspects of science literacy are present in undergraduate STEM students' writing (Miles, Huberman & Saldana, 2014). The combination of deductive and inductive coding has been used to demonstrate rigor in thematic analysis (Fereday & Muir-Cochrane, 2006). Thematic analysis is a search for the themes that emerge through the reading and re-reading of the data; these themes are used to describe the phenomenon, in this case, the manuscript-writing process (Daly, Kellehear, & Gliksman, 1997; Aronson, 1995).

Analytic memos were used to track the transcribing and coding process. The analytical memo writing process, tracked my thinking process throughout the analytical process. These memos provided insight into the coding process (Flick, 2014).

Table 3.3: Deductive Codes Developed from Pilot Study Aligned with Themes. All codes appeared in multiple interviews. Codes were initially much broader but collapsed due to similarity. Working definition of codes are presented below.

Codes from Pilot Study	**Themes**
Dissonance, Knowledge Construction, Schema Repair, Superficial Learning, No New Research, Omnipotent in Science	Students enter into the field literature and have to reconcile and restructure information. *(Science as Access)*
Credibility, Variability, Consistency, Support, Source	Students gauge credibility through what they think is important. *(Science as Access)*
Incorporate Own, Interpret Own, Comprehend Own, Incorporate Other, Interpret Other Comprehend Other	Students making meaning/understanding of their own research includes understanding research of others. *(Science as Access)*
Convention, Statistics, Visual Representation, Experimental Design, Writing for Grade Writing Style, Peer Review	Students write for conventions not for science literacy. (*Science as Process)*

First Cycle Coding. Each interview transcript and artifact were coded line-by-line and coded in short phrases as to thoroughly code the interview and in order to demonstrate rigor and attention to detail via descriptive coding methods (Saldana, 2013). For first cycle coding, in vivo coding was used. In vivo coding is an inductive process and allowed me to generate codes that represent the phrase/information provided by the participant (Saldana, 2013) that preserved participants' voices. In addition to in vivo coding, codes that were developed from the pilot study driven by the conceptual framework were applied in a deductive manner. Using both in vivo and deductive coding, allowed me to determine patterns in the data between the codes developed in first cycle coding by relating those codes and creating categories. These categories contained collapsed codes (different codes with the same meaning summarized into one code) after the second round of analysis (Charmaz, 2006, as cited in Saldana, 2013).

I analyzed the data as complete cases for each individual participant. For example, a complete case would include the participant's: (1) the pre-interview, (2) rough draft of the manuscript-style writing assignment (3) reflection 1, (4) think-aloud peer review interview transcript, (5) reflection 2, (6) final draft of the manuscript-style writing assignment, and (7) the stimulated-recall interview transcript. A description of each research question, data source, and analytical technique can be seen in Appendix I. Starting with one participant's (Christie's) case data and using both deductive and inductive coding as described above, the resultant coding scheme produced 46 total codes, 11 of which were developed from the pilot study (Table 3.3). This coding scheme was then tested against the other seven participant's data still allowing for additional codes to emerge (Table 3.4). A combined coding scheme was then constructed (Appendix H).

Table 3.4: Emergent coding scheme for Christie's Pre-Structured Case. There is a total of 46 codes from across 7 artifacts.

Code	Definition
Interaction	in relation to the conceptual framework, discussion of figure
Interconnectedness	description of conceptual framework figure
Public Communication	communicating science to the general public
Access	ability to gain either physical or conceptual access to literature
Applicability	the ability for the participant's to apply the science content to life or perceived usefulness
Ability	skill level of the participant to effectively meet conventions within the field
Jargon	technical science language
Discourse	the ability to participate and engage in science language and culture
Interest	the participant's interest in the subject matter
Conventions	technical requirements of science technical writing
Technical skill	describes a lab skill
Interpret Own	the participant's ability to interpret their own research/results
Comprehend Own	the participant's ability to comprehend and understand their own research
Minor Edits	defined as grammatical edits, aesthetic edits, minor change (e.g. word choice)
Dissonance	the participant's inconsistency between practice and beliefs around science technical writing
Major edit	defined as structural edits (e.g. flow), clarity, content addition/deletion
Detail	participant describes appropriate amount of detail
Transfer	Participant draws on prior knowledge and applies it to their writing context
Instructor Expectation	an expectation set forth by the instructor of the lab
Convention vs. Instructor Expectation	defined as when an instructor expectation does not match field conventions (example: p-values presented in tables as opposed to results text)
Confidence	the participant is confident in their ability
Experience Limitation	the participant recognizes that they have limited experience and that it may impact their research
Rubric Guidelines	follows the prescribed content necessary per the rubric
Source	primary/secondary literature used to support argument
Feedback Addressed	the participant made changes based on feedback received from instructor/peer

Interpret Other	the participant's ability to interpret data presented in other research papers, primary literature results
Comprehend Other	The participant's ability to understand and comprehend the research or writing of other researchers
Significance	related to sociopolitical factor; the participant's explanation of how their research demonstrates a connection to a larger societal issue (e.g. crop loss)
Literature Search	describes the process the participant used to look for primary literature
Argument	information included to develop an argument for the study
Credibility	in relation to primary literature used for argument development
Abstract/Introduction	sourcing information from the abstract or introduction of primary literature
Superficially Sourced	information that was sourced without being evaluated for credibility
Credibility Criteria	a participant's criteria for evaluating literature for credibility
Hypothesis	describes a participant's method for developing a hypothesis for their research study
Disdain	describes a participant's frustration with the process/part of the process of writing in science
Method Elimination	a methodological change to the experiment
Proposed Experiment vs. Actual Experiment	participant's negotiated changes made to methodology
Statistics	the participant describes a statistical interpretation, method, or result
Writing to Rubric	the participant is writing to meet the demands of the rubric
Trend	the participant describes a trend in their data analysis
Unexpected Results	the participant describes results that do not meet their expectation based on their hypothesis
Human Error	the participant's attribute experimental limitations to human error and not a biological limitation
Situate Results	the participant has to fit their experimental results into the existing literature by comparing and contrasting results
Competing Results	the participant's experimental results do not match the consensus of the field
Incorporate Other	describes how a participant is actively using the literature/source

Thirty-five additional codes emerged across the seven other cases. Table 3.5 lists these coded and provides a description of each. Also, five additional deductive codes from the pilot study emerged in the other cases.

Table 3.5: Emergent additional coding scheme and definitions for the remaining seven participants. 35 additional codes emerged. In addition, five more deductive codes developed from the pilot study emerged. These codes were in addition to the codes that emerged from Christie's pre-structured case study.

Code	Definition
Writing for a Grade	the participant discusses writing their paper towards instructor expectations
Peer Review	the participant discusses the in-class peer review or think-aloud peer review process completed as part of the study.
Scientific Process	the participant describes the traditional scientific process including hypothesis generation, experiments, and why one does science
Instructional Learning	references science that was learned in a traditional classroom
Experiential Learning	references science/science that was learned through experiences
Literacy	being able to read and write in a discipline including science
Analysis	the participant describes an analytical process not related to statistical analysis. (e.g. chlorosis rated on a qualitative scale or table and graph construction).
Time Demand	the participant references time restriction or time to complete a task while writing the paper.
Models	the participant refers to utilizing other models of writing to help understand their own writing demands
Limited Search	a participant does not actively search the literature
Agriculture	the participant draws a direct link to an agricultural significance related to the research
Self-Edit	the participant edits their own paper during think aloud
Iterative Practice	a participant refers to doing a task multiple times to get better at the said task
Convention-No	the participant describes an incorrect approach/misinterpretation to a convention
Communication	a participant describes being able to effectively communicate their science in writing.
Indicator	the participant describes indicators of credible literature and research

Prior Knowledge	the participant describes something that they knew prior to the experiment.
Literal Definition	the participant uses a literal definition of literacy (e.g. being able to read and write)
Self-reflection	a participant describes reflecting on their own writing process based on completing a peer review
Outline	a participant describes the method they used to draft their paper.
Political Influence	a participant describes how science can be influenced by/influence politics.
Delegate-In Lab	a participant describes completing one part of the lab as opposed to contributing to all methods completed in the lab. Adds to a lack of understanding the methods.
Procrastinate	a participant describes procrastinating on writing.
Time Management	a participant described their process of managing their time to complete/not complete tasks
Search Engines	a participant describes the types of search engines that they used to perform literature searches (e.g. WVU Library page, Google Scholar, Ebsco Host, Web of Science, etc.)
Self-Generated Hypothesis	a participant describes formulating a hypothesis based on beliefs rather than on literature.
Over Confident	a participant describes being confident in writing while also demonstrating multiple errors when describing conventions about scientific writing.
Independent	the participant describes domains of the conceptual framework as being their own entity (e.g. not integrated with one another).
No Additional Research	the participant did not do additional research for the discussion section of the paper. (e.g. used same sources as those used in the introduction).
Alignment	a participant describes alignment of sections in the scientific paper (e.g. the methods described match the results reported).
Knowledge Construction	a participant describes how they are putting together pieces of knowledge to understand a topic.
Optimization	a participant describes repeating experiments until there are reproducible results.
Inconsistency in Instruction	a participant describes different expectations for different instructors (e.g. citation format or data representation)
Future Directions	a participant describes the next experiment they would carry out based on their results and interpretation of their current data.

The rubric was analyzed once and applied to all eight cases for indications of science literacy using the same coding scheme.

Upon completion of first cycle in vivo coding, the codes were collapsed across one another, thus grouping together like codes and codes which represented the same information using different codes. For example, the codes access to language and discourse were combined into one code, discourse; this was done because the code access to language is a discourse issue thus representing the same information. This code mapping allowed me to see the iterations of the coding process as they occurred. For example, iteration one would be a list of the codes that were originally generated through the first pass of coding, whereas iteration two collapsed the codes and grouped them with overarching themes developed from the data (Saldana, 2014). This grouping allowed me to look at initial groupings or themes that make themselves apparent through initial coding of the data.

Second Cycle Coding. For the second cycle of coding, the method of axial coding was applied. Axial coding is defined by Strauss and Corbin (1990) as "a set of procedures whereby data are put back together in new ways after open coding by making connections between the categories" (p. 96 as cited in Kendall 1999). Axial coding allowed me to start to bring together different codes to build categories/meaning. The axial coding was done across all eight participant cases to build themes across the data.

As part of the axial coding process, I condensed codes into conceptual categories aiding in the construction of broader themes. The codes were grouped based on conceptual patterns that emerged. For example, the codes *analysis*, *competing results*, *statistics*, *unexpected results*, *human error*, *interpret own*, and *trend* were combined because they indicated a broader theme that I inferred as: *Students have difficulty interpreting statistical results, particularly when they were unexpected results.* Then I determined that this theme aligns with Science as Process domain of my conceptual framework of Science Literacy.

The data was analyzed until it reached theoretical saturation. Theoretical saturation is defined as analysis is done until it leads to no more insight (Flick, 2014). In total, through the process of axial coding, nine total themes emerged, eight of which I determined aligned with a single component of the conceptual framework. The ninth did not align with only one component of the conceptual framework. This theme involved the students' perceptions of each domain and thus aligned to their overall writing process, not necessarily the conceptual framework itself.

Methodological and Analytical Limitations

The limitations of the study include researcher bias. As an instructor in the course during past iterations, I have an insider point of view that may indirectly influence my analytical approach. To limit this researcher bias, I acknowledged it and I remained focused on the data. By building the analysis based on presenting illustrative examples from the data, this will allow me to remain focused on the data thus limiting my researcher bias.

Another limitation of this method is that a shallow understanding of the phenomena being studied can be inferred (Miles, 1990). In order to combat this limitation, there were eight different participants in the investigation. The diversity in participants lends itself to understanding a richer context of how introductory STEM majors demonstrate aspects of science literacy in authentic writing processes.

Lastly, this study is exploratory in nature, therefore the results of this study cannot be extrapolated to find meaning across different contexts, rather, it explores what aspects of science literacy are demonstrated during the authentic writing process. The method of a pre-structured case study lends nicely to exploratory research.

Summary

This study utilized a qualitative research design of the pre-structured case study. It explored an authentic manuscript-style writing process to study which aspects of science literacy are demonstrated throughout the writing process. I attempted to explore where aspects of science literacy can be seen through a series of interviews, reflections, and document analysis. There was a total of eight participants who completed the study.

Chapter 4: Findings

In this chapter, I discuss the findings that emerged from my analysis. The data analyzed for this study included: interview transcripts, written reflections, and student artifact data from the manuscript-style writing assignment previously described. Eight participants who completed the study, and data pertaining to their individual writing process was analyzed to address the following research questions.

1. How do students demonstrate science literacy at different points in the writing process as they work towards completing the manuscript-style writing an assignment?
2. How do course artifacts (manuscript drafts and the course rubric) related to this assignment demonstrate science literacy?
3. How do students talk about what it means to be scientifically literate?

Each participant's writing process was analyzed using both deductive and inductive coding methods driven by the conceptual framework for first-cycle coding. In coding my data, recall from chapter three my analytical approach involved two cycles of coding. After the completion of first-cycle coding, axial coding methods were utilized for second cycle coding. The codes from the first cycle were collapsed and conceptually organized to generate themes seen across the analyzed data. In total, through this process of axial coding, nine themes emerged (Table 4.1). The ninth did not align with only a single component of the conceptual framework. Rather, this theme involved the students' perceptions of each domain and thus aligned to their overall writing process, not necessarily the conceptual framework itself. All nine themes were seen across the eight participants. Lastly, the rubric was analyzed using the codes developed based on the conceptual framework for aspects of science literacy. Additional course artifacts (manuscript drafts) were also analyzed for aspects of science literacy.

A total of nine themes emerged from the data: (1) Students have difficulty entering into the literature and successfully finding credible sources, (2) Students develop weakly supported arguments, (3) Students' prior knowledge and experiences shape their working knowledge of the experiment and their ability to enter into the discourse of the field, (4) Students display a strong understanding of traditional scientific processes such as generating hypotheses, completing an experiment, and following models, (5) Students have difficulty interpreting statistical results, particularly when they were unexpected results, (6) Students feedback and revisions were influenced by their own understanding of the experiment, the assignment expectations, and conventions in scientific writing, (7) Students understand the purpose of scientific writing, but still conform their writing to meet rubric expectations, (8) Students make limited connections/reference to a larger significance of science without direct prompting, (9) Students attitude and perceptions towards their written assignment indirectly influenced their performance. The codes associated with each theme and its corresponding domain of the conceptual framework can be found in Table 4.1.

Table 4.1: Emergent Themes of the Cross-Case Analysis Aligned with the Domain of the Science Literacy Conceptual Framework. There was a total of nine emergent themes, eight of which aligned with a domain of the science literacy conceptual framework. The codes that support each theme are highlighted.

Theme	Codes Associated with the Theme	Domain
Students have difficulty entering into the literature and successfully finding credible sources.	No additional research, Access, Superficially sourced, Literature Search, Limited Search, Search Engines, Source, Credibility, Indicator, Credibility criteria	Science as Access
Students develop weakly supported arguments.	Abstract/Introduction, Comprehend Own, Self-Generated Hypothesis, situate results, incorporate other,	Science as Access

	argument, interpret other, comprehend other	
Students' prior knowledge and experiences shape their working knowledge of the experiment and their ability to enter into the discourse of the field.	Discourse, applicability, convention vs. instructor expectation, literacy, transfer, ability, prior knowledge, literal definition, knowledge construction, instructional learning, experiential learning, inconsistency in instruction, experience limitation, jargon, dissonance, interaction, independent, interconnectedness	Science as Access
Students display a strong understanding of traditional scientific processes such as generating hypotheses, completing an experiment, and following models.	Technical Skill, Method elimination, detail, hypothesis, optimization, proposed experiment vs. actual experiment, scientific process, models, delegate in lab.	Science as Process
Students have difficulty interpreting statistical results, particularly when they were unexpected results.	Analysis, competing results, statistics, unexpected results, human error, interpret own, trend	Science as Process
Students feedback and revisions were influenced by their own understanding of the experiment, the assignment expectations, and conventions in scientific writing.	Feedback addressed, self-edit, convention no, peer review, convention, convention no, self-reflection, minor edits, major edits	Science as Process
Students understand the purpose of scientific writing, but still conform their writing to meet rubric expectations.	Alignment, rubric guidelines, outline, writing for a grade, iterative practice, writing to rubric, communication, public communication, future directions, instructor expectation	Science as Process
Students make limited connections/reference to a larger significance of science without direct prompting.	Agriculture, Political influence, significance	Science as a Sociopolitical Factor
Students attitude and perceptions towards their written assignment indirectly influenced their performance.	Disdain, interest, time demand, confidence, over-confidence, time management, procrastinate	

There were three themes associated with the *Science as Access* domain. The first theme: *Students have difficulty entering into the literature and successfully finding credible sources* describes the students' ability to enter into the literature and successfully find primary research literature that is credible. The expectation set forth by the course is for students to be able to find credible primary literature to support their findings. An example of this can be seen in Jen's description of how she locates primary literature: "I look for my source on the library website…but I have never really looked to see if a journal [article] is credible." This theme was supported even when students had background using the primary literature such as Christie and Anna thus suggesting that discourse is guiding the students' understanding of the literature.

The second theme associated with this domain: *Students develop weakly supported arguments* is related to the first theme and involves students using literature to supports basic facts as opposed to using the literature's findings to guide their argument. In his discussion of how he used the literature to build an argument, Sean cited using the background information: "I think all of my references were all for background information and the beginning of the experiment usually to just get a general understanding." All of the students except Anna described using the introduction sections to source information for their argument construction alluding to a lack of discourse. While the students did describe using the introductions, they all could articulate why you would use primary literature to construct an argument.

The third theme associated with this domain is: *Students' prior knowledge and experiences shape their working knowledge of the experiment and their ability to enter into the discourse of the field*. This theme supports the constructivist viewpoint that students bring experiences and prior knowledge with them into the classroom. Sean demonstrated this is he drew on is upbringing, with his father being a high school science teacher; for example, Sean described "my dad was a science teacher, so I was raised in science." Other students drew on different experiences such as prior instruction from different major, such as Tim, who drew on his background in engineering and Anna who drew on her previous education as an English major.

The *Science as Process* domain contained the most themes, four. The first theme: *Students display a strong understanding of traditional scientific processes such as generating hypotheses, completing an experiment, and following models,* represents the students' ability to follow the traditional scientific method and skills developed across the K-12 science curriculum. All eight students were confident in their ability to complete the methods of the experiment until they wrote their manuscript and did not have significant results to report. All eight students were able to discuss their experiments in terms of independent and dependent variables, controls, and constants. All of the students were also confident following a model of a manuscript. Joey, for example, drew on his methods to model the other sections of his written manuscript; whereas, Jen was able to draw on the rubric as a model.

The second theme associated with this domain: *Students have difficulty interpreting statistical results, particularly when they were unexpected results* represents how students interpreted their experimental findings, more specifically the statistical analysis of their data. All eight students reported having insignificant data. Christie described that is was "a bummer that I didn't get more significant results like she was expecting there to be…all the categories were all decently close if you look at the graphs…which made me think I did something wrong, or I guess maybe it just didn't correspond with phosphorous deficiencies." Sean also described having difficulty interpreting statistics where he misinterpreted statistically significant data for insignificant data and further described his insignificant data as human error. This description of the insignificant results was consistent across all eight cases and further demonstrated that students had difficulty interpreting their statistical analysis.

The third theme associated with this domain: *Students feedback and revisions were influenced by their own understanding of the experiment, the assignment expectations, and conventions in scientific writing* represents a convention in science manuscript writing, peer review and revision of their drafts. Students demonstrated that their overall ability to give feedback and address feedback was influenced by how well they understood the experiment. For example, during the think-aloud protocol, Stacey and Anna were able to give differing levels of feedback. Stacey had a strong understanding of the experiment and was able to provide Anna with feedback regarding the analysis and methods whereas Anna was only able to provide feedback on the structure and flow of Stacey's manuscript. This was also demonstrated in Tim and Jen's think-aloud interview where Tim gave more in-depth feedback versus the structural and grammatical feedback provided by Jen.

The fourth theme associated with this domain: *Students understand the purpose of scientific writing, but still conform their writing to meet rubric expectations* encompasses how students talk about scientific writing and its conventions, but often conform their writing towards the grader and rubric expectations. During David and Joey's think-aloud, both students discussed how they understood the convention and then how they conformed their understanding to meet the expectations of the grader and rubric. Furthermore, Christie described understanding the convention of how to report statistics but morphed it to meet the demands of her assignment, "The T.A. said it was really nice when they [the p-values] were in a table format. She said that, otherwise, I would have put it [the p-values] in the text. I probably should have put it in there too though." Christie was aware of how p-values are traditionally represented based on the conventions of the field but still incorporated them to meet the expectations of the assignment.

The *Science as a Sociopolitical Factor* contained one theme: *Students make limited connections/reference to a larger significance of science without direct prompting*. This theme describes the students' ability to discuss a sociopolitical factor when directly asked about it during the stimulated recall interview, but it was not made explicit in their written artifacts. Six out of eight students were unable to incorporate a sociopolitical topic into their written document, but all eight students were able to discuss this when asked how their manuscript directly related to a larger societal issue. For example, Joey was able to discuss how understanding nutrient deficiencies could lead applications in different regions "Understanding nutrient deficiencies in different parts of the world like in tropical regions or tundra regions where these nutrient deficiencies will help us determine best conditions for plant survival and increase crops". While Joey was able to discuss in his interview, he did not include this connection in his written artifacts. Christie and David were the only two participants who directly incorporated sociopolitical topics in their written artifacts and used literature to support it as well as discussed it in their interview.

In addition to the eight themes that aligned with the conceptual framework, there was an additional theme that did not align but influenced the domains. This theme was: *Students attitude and perceptions towards their written assignment indirectly influenced their performance*. This theme was seen across all eight cases in different contexts. For example, Sean demonstrated this as he talked about his ability to write "I am actually more into the short and concise writing, I feel like once you get wordy that is when it is not as good anymore…but I feel like I get docked points for this but that is the way I believe to write and that is the same with my references, I don't believe in just sprinkling in random references." Here Sean is demonstrating this theme as overconfidence in his abilities. Other students also demonstrated overconfidence, but it was often related to their ability to write their methods section based on the lab manual such as Jen, Stacey, or Anna, but their written methods were often missing key methods and detail. David was confident in his ability to write the methods because he drew on previous knowledge that he should write his methods as they were completed in the lab. He discussed in his reflection, "The methods section was quick to write because I wrote it in steps as we completed the lab" All eight students' performance on their written manuscript was influenced based on their attitude and perceptions of the assignment and task itself.

All nine themes were evident in each participant's data set. A demonstration of these themes is presented in the cases that follow. These findings are presented as individual cases following a pre-structured case study format (Miles, 1990) with three components: (1) participant's definition and conceptualization of science literacy (RQ 3), (2) emergent aspects of the participant's science literacy as demonstrated throughout the writing process aligned with the three domains of science literacy as presented in my conceptual framework for this research (RQ1/RQ2, Figure: 4.1), and (3) interesting trends seen in the data unique to the participant. Each participant was given a pseudonym to preserve anonymity, and these pseudonyms are used in the case descriptions that follow.

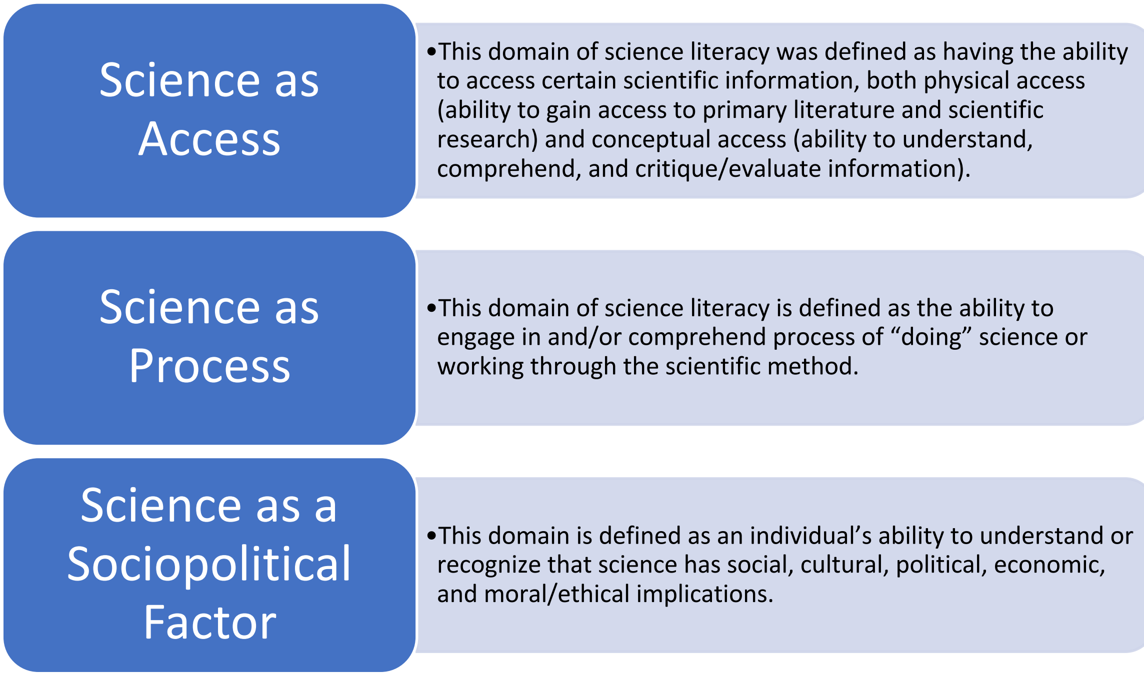

Figure 4.1: Definitions of Conceptual Framework Domains.

Case #1: Christie

1.1 Background

Christie was an undergraduate psychology major. During her screening interview, Christie described her science background as moderate; however, when asked to describe her confidence in her ability to write about science, she described her ability as fair. She stated that her boyfriend has influenced her the most in her science learning. She described how she learns science through her experiences explaining mechanical and biological mechanisms to herself and others; she further described that she and her boyfriend enjoy challenging one another to figure out how things work when they do not understand. Lastly, when asked what out-of-school experiences have shaped how she best learns science, Christie described observation and experiential learning. For example, she described learning about science by observing different organisms during a hike, or by understanding how her own body works. Christie was very successful in both the pre-requisite Biology 117 and in her English 101 course, where she earned A's in both.

1.2 Christie's definition and conceptualization of science literacy:

During her pre-interview, Christie was presented with an image of the conceptual framework and asked to describe what she thought the image was showing her. Christie responded with:

> It is how science literacy interacts with each of these points, how it interacts with science as access, science as a process, and science as a sociopolitical factor. They are all connected and they each…science as access is connected as science as a process, which is also science as a sociopolitical factor and vice versa for all three of them. [Christie pre-interview July 2017]

She then went on to elaborate on how each component of the framework might function.

> Well you have to know science literacy and well you have to know that science is a process to know and understand reading and writing science literacy; which has a significant effect on the science as sociopolitical factor, you have to be able to talk about and like express it to the public and make your things known. Your contributions are known, advance science more, Science as Access, I don't know. [Christie pre-interview July 2017]

Christie identified specific aspects of science literacy, such as understanding the scientific method as a process, and that reading and writing in science were critical to pushing the field forward.

Christie was also asked to define science literacy:

> I think science literacy is not just being able to read and understand scientific articles, but it is how you show your work to others, how you present it and also contributing to society as a whole and showing how you did that talking about it. [Christie stimulated-recall interview July 2017]

Here, Christie's definition demonstrates the main essence of how science literacy is defined in this work. She described it as being able to read and understand scientific articles, (which correlates to *Science as Access*), how science would contribute to society) which correlates to *Science as a Sociopolitical Factor*), and lastly, to discuss what you did and how you did it (which correlates to *Science as Process*).

1.3 Emergent aspects of Christie's science literacy aligned with the three domains of my conceptual framework

1.3.1 Science as Access:

Through analysis of all of Christie's data, all three themes associated with Science as Access (Table 4.1) emerged during her manuscript-style writing assignment. These themes include: (1) *Students have difficulty entering into the literature and successfully finding credible sources*, (2) *Students develop weakly supported arguments*, and (3) *Students' prior knowledge and experiences shape their working knowledge of the experiment and their ability to enter into the discourse of the field.* Illustrative examples of how these themes emerged will be demonstrated in the following presentation of the results.

When talking with Christie during her stimulated-recall interview, she discussed having a good grasp on how to find sources and was able to articulate her search process clearly.

> I would Google like phosphorous plant deficiencies or just phosphorous deficiencies, and I would get all kinds of results, so I would scroll through those and find which ones were more relevant to my experiment, click on them, and try to read them the best that I could, and find information that would help out most. One reference was telling me all about the effects on different macronutrients on the plant… [Christie stimulated-recall interview 7/30/17]

This is an example of how Christie had difficulty entering into the literature thus an illustrative example of Theme 1: *Students have difficulty entering into the literature and successfully finding credible sources*. She described trying to read the literature the best that she could but Christie was not always able Christie then discussed what parameters she used in order to find good sources.

> Peer-reviewed and is from a scientific journal. [Christie stimulated-recall interview July 2017]

Even though Christie used parameters such as peer-reviewed and published to limit her search for credible sources, Christie's statement shows that she assumed that her search would only result in credible sources. It is likely that this assumption limits her ability to recognize that even peer-reviewed literature can sometimes not be credible. She then went on to discuss the results of her search, and the research that she found pertaining to her experiment.

> I found two articles relating to a phosphorous deficiency on the library website… [Christie stimulated-recall interview July 2017]

While she was able to find two different sources about her experiment, Christie described her frustrations with being able to access the information conceptually.

> I used a piece of information from the first few paragraphs. It was easier to do this, and not dig through the entire paper only to come out frustrated and confused. [Christie stimulated-recall interview July 2017]

Here, Christie's statement suggests that she does not have an effective strategy to read through the primary literature, and when she does, she often becomes frustrated. Following this, Christie further highlighted her frustration with not being able to effectively and efficiently read the primary literature.

> This frustration is due to my lack of efficiency in reading and interpreting other research papers. I find myself getting lost in the sea of scientific terms and ideas… [Christie stimulated-recall interview July 2017]

> The process of writing the introduction would be much less painful if I knew how to skim research for the information correctly. [Christie written reflection 1 July 2017]

Christie also attributed her approach to writing in science to her difficulties in reading and finding information in the literature. For example, she tends to pull her cited information from the introduction in order to support facts rather than form the findings of the primary research article.

> Because I have trouble reading and finding the information I need in a scientific article, I will take one of the sentences from like the first page, some information because I get frustrated if I continue in the paper. [Christie stimulated-recall interview July 2017]

Christie has identified where her limitations are accessing primary literature. She recognized that she is unable to immerse, comprehend, and interpret primary literature fully. As opposed to not using primary literature at all, Christie focused on the sections of literature that she can access, including the abstracts and introduction. This was made apparent in her introduction of her manuscript-style assignment paper where she did not focus her introduction on phosphorous and phosphorous deficiencies, but instead used the primary literature to build a background about deficiencies in general.

> Some signs of an iron deficiency include chlorosis, or the yellowing of the leaves (Sanchez et al., 2014). Limited amounts of nitrogen can lead to a loss of plant biomass, slow growth rates, and damage due to an increased oxygen level (Rubio-Wihelmi et al., 2011). [Christie Rough and Final Manuscript Drafts, July 2017]

Within this example from her final draft of the manuscript-style writing assignment, Christie demonstrated that she can incorporate primary literature into her science writing; however, she did not demonstrate that she can effectively use the literature to build an argument as to why she would study phosphorous deficiency in plants.

While Christie had difficulty demonstrating how to use the sources to build her argument effectively, she did articulate how she was expected to integrate the literature in order to build her argument.

> Whatever results they got from their experiment, so if they had more chlorophyll in a less deficient plant, then I would make my hypothesis, less deficient plants would have more chlorophyll because one, it is what they said and two, it just makes sense. [Christie stimulated-recall interview July 2017]

Christie's description suggests that she is using other research to construct her argument leading to the development of her hypothesis. Her description of how she used the primary literature to formulate her hypothesis also suggests that she has the makings of constructing a scientific argument.

When asked how she would incorporate sources into her introduction, Christie described where she likes to incorporate her sources:

> And then you follow up with the source. So, I put the source in the middle if that makes sense, in the middle of my idea most of the time. [Christie stimulated-recall interview July 2017]

Christie was able to describe using the source to support a claim, but she also explained the source by putting it into the middle of her idea. This is how Christie described framing a citation. This discussion also suggests that Christie has an understanding that the literature should be used as support, also indicative of building an argument.

1.3.2 Science as Process:

Through analysis of all of Christie's data, all four themes associated with *Science as Process* emerged (Table 4.1). The emergence of these themes is demonstrated in the case below. In her written reflection of her rough draft, Christie described her statistical analysis that she included in her methods section:

> Paired two-sample t-tests were used, analyze the data collected through data analysis on Microsoft Excel; however, I am not entirely sure that I was correct, because the data was automatically running for us [Christie's written reflection, July 2017].

While Christie acknowledged and recognized that she was expected to run t-tests, the data was not paired; therefore, her description of the statistical test was incorrect. Furthermore, Christie further discussed during her think aloud protocol, her clarity when discussing her methods used for the experiment. In particular, she went back and forth on the proper level of detail that should be included, so that the reader could reproduce her methods, a convention in the field.

> I did not quite go root to tip though, it was kind of like from soil to tip, so I should probably say that. I mean, we did not pull the plants out and do the roots — soil to tip with a ruler in centimeters [Christie's Think-Aloud interview July 2017]

She then went on to mention that while writing the methods out, she sometimes struggled with understanding why, and how she was doing the experiment, and that this limited her ability to interpret her data within the discussion section.

> It is hard for me to understand what I did in the experiment; so, it is shown in the discussion, when I am trying to talk about it [Christie's Think-Aloud interview July 2017].

Christie's struggle with understanding the experiment rolled over into the results section of her paper. When discussing the results section of her paper, Christie alluded to being able to understand how to read the data. More specifically, she described being able to more easily interpret the data once it was in a familiar format, graphs, and tables.

Interpreting the data was easy for me once I had it into graphs and tables [Christie's Think-Aloud interview July 2017].

Once the data was into a recognizable format, Christie was able to draw predictions based on the bar graphs, and the standard error.

> It was a bummer that I did not get more significant results. I was expecting there to be less close data between the half, complete, and deficient categories. They were all decently close if you look at the graphs [Christie's Think-Aloud interview July 2017].

While this was true of her data, the following exchange between myself and Christie indicated that she was having difficulty understanding how to interpret statistical tests.

> Christie: The p-values were not significant for any of the treatment groups when tested against one another. That makes me sad.
>
> Researcher: What might this suggest?
>
> Christie: That we did it wrong. [Christie's Think-Aloud interview July 2017]

This indicates that while Christie was able to identify if a p-value was significant or not, she was not able to interpret what that might mean. For example, what Christie did not demonstrate understanding of was that the species of plant used, *Brassica rapa*, was a species of weed, so perhaps there was not a need for as many nutrients, or that the sample sizes might have been too small. Instead, Christie assumed that there were no statistical differences due to experimenter error.

Even though Christie had difficulty interpreting her statistics, she effectively reported the trends in her data. For example, Christie compared treatment groups:

> I tried to put in sentences that were not discussing the results but would help conclude later like, the tallest plants had 50% deficiency, followed by the positive control of 0% deficiency, but I did not use any numbers when I made that sentence [Christie's Think-Aloud interview July 2017].

Christie's ability to report trends fits the convention of the field and meets the demands of the rubric. When discussing the discussion section of the paper and how she wrote that section, Christie described it as space to:

> To compare your work with others, how did it measure up, did other people get the same results as you, and usually, I mean if you have similar results with other people. I think that makes your work a little bit more, well no I do not want to say it makes it more credible, because you could have been studying something new and do something that nobody else has [Christie's Think-Aloud interview July 2017].

Even though Christie reported that the discussion was a space where she could compare her results with other studies, Christie did so limitedly. For example, in her written final draft, she effectively compared and contrasted her height data to a primary research article.

> Plant without any phosphorous deficiency grew the tallest and had the most amount of leaves. These findings were consistent with Rubio et al., regarding plants growing more efficiently without a phosphorus deficiency. 0% deficiency did not have the highest number of stomata, or total chlorophyll, which was not consistent with Rubio et al. [Christie's Final Manuscript July 2017]

In this part of her final draft, Christie was able to demonstrate that she understood how to compare and contrast her results; however, it was limited because she only compared and contrasted one of four treatments, thus leaving the majority of her results not interpreted.

Further into Christie's discussion section of this final draft, however, her difficulty understanding the experiment and what the results meant reemerged.

> Many of the unexpected results may have been due to human error while experimenting. The stomata were challenging to see and count with the human eye, especially for the inexperienced. The acetone for the chlorophyll measurements had to be replenished and evaporated quickly, which probably interfered with the

> concentrations, and therefore interfered with the data [Christie's Final Manuscript July 2017].

Here, this shows that Christie was having difficulty interpreting her results outside of everything being attributed to human error. These consistencies in attributing the outcome of the experiment to human error suggest; that Christie has a limited understanding of how to interpret her data, even though she was able to navigate some of the conventions of writing a discussion section where the data interpretation would appear.

1.3.3 Science as a Sociopolitical Factor:

Throughout her writing process data and interview data, Christie demonstrated an understanding of the connection between social issues and studying plant nutrition. Therefore, the theme *Student make limited connections/references to a larger significance of science without direct prompting* was not present in Christie's data. For example, in her stimulated recall interview, Christie described how farmers could be affected given inadequate resources, which ultimately lead to crop loss.

> Crop loss is a huge problem, and it is devastating for many people because food is shipped out everywhere all over the world…so if deficiencies in nutrients are killing your crops and you do not know it, I mean it is essential to study that [Christie's Stimulated recall interview July 2017].

Christie further articulated this connection in the introduction section of her final draft of the manuscript-style assignment artifact, linking phosphorous-deficient soils to the overall effects that it had on plants, thus building her argument as to why it would be critical to study nutrient deficiencies and phosphorous more specifically.

> This can especially be a problem in areas of farmers with poor resources, so much so that genotypic alteration efforts have been made to make plants more tolerant of phosphorous deficient soil (Wissuwa, 2003) [Christie's Final Manuscript Draft July 2017].

While Christie did identify primary research articles that directly tied a sociopolitical issue to her experimental context, Christie did not discuss this in her introduction of her final draft artifact. Her final draft artifact, as is a convention in the field. Her final draft showed that she started too broad when providing the context of the study.

Furthermore, throughout her interview process, during both the think-aloud protocol and stimulated recall interview, Christie mentioned that she recalled reading literature that pertained to specific crops used in agriculture; which she further used to tie together the social aspect of her experiment. For example:

> I think I said corn because there was an article I came across that was focused on corn and phosphorous [Christie's Think-Aloud interview July 2017].

She also mentioned that understanding how phosphorous deficiencies in relation to corn, would allow for increased crop yields.

> Plants that are often used in agriculture, such as corn, would be better to study so that we can grow more of it for our use [Christie's Final Manuscript Draft July 2017].

Christie was able to connect the need for understanding phosphorous deficiencies to a sociopolitical context (agriculture and crop yields); however, when talking about this, she did not feel that she had expertly drawn the connection in her writing.

> Well, I should have done a better job connecting this with the outside world, and people in the discussion, and making it and talking about and how it would help poor farmers. I

> did not do a great job connecting the outside world with that and making it a better argument on why it was essential to the study [Christie's Stimulated-Recall Inteview July 2017].

Here, Christie was able to identify that the sociopolitical link is critical for developing the argument she is making for studying plant nutrients. She also suggested that while she understands this connection, she still had difficulty effectively integrating the sociopolitical topic into her argument, even though she was able to articulate and support it using the literature.

1.4 Interesting Trends:

One interesting trend evident in Christie's data centered on a tension between understanding the conventions of scientific writing and meeting the expectations of the person who would be grading her work. For examples, while Christie appeared to have a firm grasp on the conventions of scientific writing, and the convention in which researchers report statistics; Christie described forgoing that knowledge, in order to tailor her assignment to the instructor grading the assignment.

> The TA said that it was nice when the (p-values) were in a table. She said that I do not know, she suggested that otherwise, I would have put it in the text. I probably should have put it in the text to [Christie's Think-Aloud interview July 2017].

She further went on to say:

> Yeah, I should have included it when I stated if they were significant or not. I just tailored it to the grader [Christie's Think-Aloud interview July 2017].

This suggests that Christie was putting a greater emphasis on meeting the demands of the assignment, and the expectations of the grader, as opposed to following the conventions of writing in science in which she reported being knowledgeable about.

Another interesting trend evident in Christie's data indicated inconsistency un Christie's self-reported confidence. For example, on the one hand, when asked about her confidence regarding writing about her results, Christie reported being confident in her ability to effectively analyze and report her experimental results.

> Researcher: Are you confident about your results section?
>
> Christie: Other than the stuff we were talking about, yeah [Christie's Think-Aloud interview July 2017].

Yet on the other hand, Christie also reported lacking confidence in her ability to collect and analyze her data.

> We are just inexperienced, so I just assumed that we did something wrong [Christie's Think-Aloud interview July 2017].

One further interesting trend seen in Christie's data suggested that her interest in a topic affected her interest and desire to engage with and write about the topic. For example:

> Usually, if it is on a topic that I am not interested in, to begin with because it is for school and I do not get to choose, it is just even more boring [Christie's Stimulated-Recall interview July 2017].

This statement indicates that Christie's interest in the assignment topic impacts her perception of the manuscript-style writing assignment, and thus, it is likely Christie requires some level of intrinsic motivation necessary for her to be fully engaged in the writing process.

1.5 Case 1 Summary:

Christie displays aspects of all three domains of science literacy described in the conceptual framework (Figure 4.2). While she displays aspects from all three domains, her understanding is shaped by her prior knowledge and current understanding of the experiment at hand. For example, Christie shows that she can enter into the literature and successfully find sources related to her experiment; however, she does not show that she has the necessary discourse to interpret the findings of those studies; therefore, she relies on the information presented in the introduction of the primary article. By using the literature in this manner to supper her argument, she is simply corroborating facts rather than using the results of the primary research study she is drawing up to present a strong case. This shows that Christie's *Science as Access* aspect of her science literacy is both encouraging in that she has demonstrated elements that are necessary to being scientifically literate, and at the same time, her skills and understanding in this domain have room to further develop.

Christie's data demonstrated that she had the most significant struggle with the *Science as Process* domain of her science literacy. Early on in her reflections and interview, Christie described having a superficial understanding of the experimental design. This surface understanding could partly be attributed to her difficulty interpreting the literature. Her superficial understanding of the experiment was also seen in the results and discussion sections of her final draft artifact when reporting and interpreting her results. It was not until her data was in a more recognizable form, tables, and graphs, did Christie understand her results and was then able to compare and contrast them to other studies. Christie did demonstrate however, that she does have a clear understanding of the conventions in scientific writing.

Again, like her other domain, this shows that Christie's *Science as Process* aspect of her science literacy is both encouraging in that it has elements that are necessary to being scientifically literate, and at the same time, her skills understanding in this domain have room to further develop.

Lastly, Christie was able to describe a broader Sociopolitical Factor in both her writing and her discussion with me. She was able to link understanding of how plant nutrition affects different growth and physiological processes to both an agricultural and economical application (crop loss). This application was a crop loss. Christie further supports her sociopolitical link with the primary literature. This shows that Christie's *Science as a Sociopolitical Factor* aspect of her science literacy is quite encouraging in that it has elements that are necessary to being scientifically literate.

Finally, in Figure 4.2 below, I offer a representation of Christie's science literacy as it was demonstrated in her data aligned to the conceptual framework of this dissertation study. Within these three domains, I included the themes that were evident across all sources of her data and supported by the excerpts in the case description.

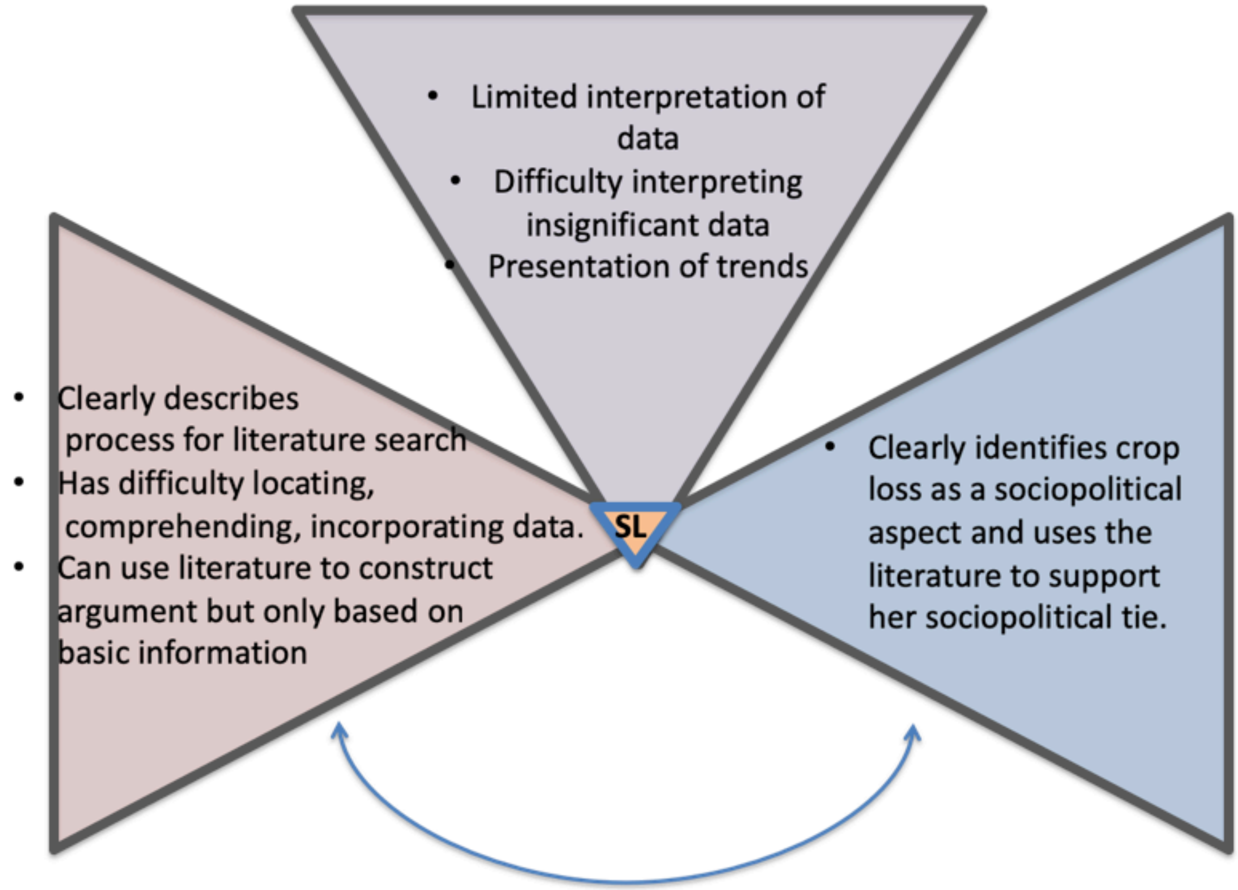

Figure 4.2: Christie's Science Literacy: Summary of Christie's science literacy mapped onto the conceptual framework. The two-sided arrow indicated a relationship between two of the domains that Christie had articulated. Specifically, Christie was able to use the literature to support her sociopolitical topic of crop loss.

Case # 2: Anna

2.1 Background

Anna is an undergraduate biology major who completed the alternative biology track intended for non-STEM majors, BIOL 101,102, 103 (lab), and 104 (lab) where she earned an A in all four courses. The course work for the BIOL 101, 102, 103, and 104 sequences are considered to be equivalent to BIOL 115. The only difference is that Anna had no previous scientific writing experience outside of BIOL 117 because the non-major labs do not incorporate authentic writing experiences. Anna had previously completed a bachelor’s degree in English and a

Masters degree in Social Work; therefore, Anna had already completed ENGL 101 and earned a grade of an A. When asked, Anna described her science background as having no science background, even though she completed a year of college-level biology. She continued to say that she does have a strong background in writing (given her English background); however, she recognized that she does not have any background in the writing conventions of science. She claims to be most influenced by her English degree in the way that she learns science and described that her prior experiences in other classes have shaped and taught her how to learn.

2.2 Anna's definition and conceptualization of science literacy:

Anna was presented with an image of the conceptual framework and asked to describe what she thought the image was showing her. Anna described the image as:

> Science literacy has three different components, and these are almost like spokes on a fan. So, they are different aspects of science literacy. It is a process, so maybe when you write, it is not just something that you write and hand in. I am not quite sure what sociopolitical factor is implying, or access, but if I must guess, maybe relating to other scientific articles or research that is in the field. I am not sure what process would be, but it is all connected in all aspects [Anna's Pre-Interview July 2017].

Although Anna did not know what each domain of the conceptual framework means specifically, she deduced that there is a component of science literacy that relates science to other science (*Science as Access*). Anna also described that writing for science literacy is an iterative process. After the study, Anna was also asked to define science literacy. Anna defined science literacy as:

> Being able to analyze and interpret data and articulate those thoughts effectively in writing [Anna's Stimulated Recall Interview July 2017].

Anna's definition morphed throughout the study to include being able to analyze and interpret data in the writing, which would incorporate aspects of *Science as Process* domain to her definition. The only connection to the conceptual framework that Anna omitted in her description was *Science as a Sociopolitical Factor*, although Anna was quickly identified a connection between her experiment to a sociopolitical factor both in her writing and during her interview.

2.3 Emergent aspects of Anna's science literacy aligned with the three domains of my conceptual framework

2.3.1 Science as Access:

Across all of Anna's interview and artifact data, two of the three themes associated with the Science as Access domain emerged. These themes included: (2) *Students develop weakly supported arguments,* and (3) *Student's prior knowledge and experiences shape their working knowledge of the experiment and their ability to enter into the discourse of the field.* Anna demonstrated a strong understanding of how to use literature, by drawing on her English degree background, but was limited by her lack of discourse in the science field, which impacted her ability to develop her argument.

Anna used the rubric to guide her literature search when she was crafting her introduction. She described the process as looking at the critical points on the rubric to help guide her literature search.

> I looked at my rubric, I figured out the questions that we needed to answer, and then I made a list of the sources that I was going to use. I went to the library website, and I looked at the primary articles, I had to go through several of them to find articles that would answer the questions that I needed and then I created this paper [Anna's Stimulated Recall Interview July 2017].

After a review of Anna's sources, they are all applicable to her experiment and the argument that she was developing. Anna also described the process of using her primary research articles to help develop her paragraphs in her introduction section.

> I answered the questions from the articles, and then I created the citations within it. Then I put them together, and I connected them with topic sentences and transitions, and then I had to change my stuff around because I did not think about from big to small, so during the final one I had to change it so that the macronutrients were discussed first versus the micronutrients stuff [Anna's Stimulated Recall Interview July 2017].

Anna described her process for not only building her paragraphs, but she also described how she is used the literature to guide her introduction. Anna's description suggested that Anna was able to incorporate literature into the introduction. While Anna's description of using literature in the introduction suggested that she understood how to incorporate, Anna only supported facts with her citations. Her literature usage suggested that Anna was limited by the discourse but did reflect that understood the convention of how to incorporate citations to construct an argument.

When she was later asked how she used citations in the discussion section. Anna described using her citations to help give her a "sounding board" to help her determine what could have gone wrong in her experiment. She described using her sources as:

> Because I did not have any plausible explanation, and whom I mean, nobody cares that a college kid wrote a paper that said that; therefore, it could be wrong, so it strengthens your paper to find those resources, and it also gives you a sounding board and ideas as to what went wrong. I could sit here all I want and say my experiment failed because we did something wrong, or whatever, but to find a source that had a reason that was also tested, and two people found the same thing, make my paper a little bit stronger [Anna's Stimulated Recall Interview July 2017].

Anna continued in her final interview, to talk about how she was able to compare her results with other studies, and why that was important to do that in her discussion section.

> I had talked to my lab TA, and one of the comments that I received in my draft was that I had not talked about magnesium in my whole discussion. I had not talked about another group of people that had done magnesium, so she prepared me for it, she was like "you are probably going to find people that had opposite results than you did," so I was prepared for it. However, honestly, this is not a sales agency; this is a scientific paper. If I were to submit this for real, like in a real scientific community, I guarantee you that like 20 people are going to write like this makes no sense. I think it is essential to offer the other perspective because you do not know what happened in an experiment. What if in 5 years from now they find something with magnesium, you know that something

> had gone in the way that we had done ours, or maybe they find some discovery, so it is important to mention the other side too [Anna's Stimulated Recall Interview July 2017].

Anna recognized that even though she did incorporate, compared, and contrasted literature with her experimental results, this discussion was guided by her conversations with her TA. While her TA guided the discussion, Anna still articulated the value comparing, and contrasting results had in terms of interpreting data. Anna also recognized the importance of peer review in the authentic scientific research and writing process.

During her review of Anna's paper, Stacey noticed that Anna needed more background information to support her argument that she was developing in her introduction.

> Stacey: I think I would also talk about the magnesium paragraph. There is something about magnesium being a component of chlorophyll or photosynthesis things and maybe talk about that because that supports the reason to do the photosynthetic pigment experiment [Anna's Think-Aloud Interview July 2017].

While Anna did include this type of background, it was focused on other macronutrients, that were not studied in their experiment, thus further suggesting that Anna does have a working understanding of how to construct the argument, but it was not focused on the macronutrient that was being studied.

Even though Anna consistently discussed having issues with conventions in the field, Anna demonstrated an understanding of how to incorporate and use sources within her written manuscript-style writing assignment.

> R: You said you looked for sources in the library's webpage. Did you use any other places to look for sources or is that it?

> Anna: Google Scholar
>
> R: When you are reading those primary sources, what part of the paper do you look for information?
>
> Anna: I mean I scan like I scan the entire thing to see that it would answer any of the questions that I had.
>
> R: Okay, so if you found something, what part of the paper would you typically pull information from?
>
> Anna: Um, it depends. Sometimes from their discussion, um sometimes I look at the results to see what they came up with [Anna's Stimulated Recall Interview July 2017].

This concept was further demonstrated in her final draft of her paper when she effectively incorporated scientific literature.

> Scientists have used a visual observation to identify deficiencies, but in order to test for pseudo deficiencies, nutrient stress, or hidden hunger, soil and plant testing are necessary (McCauley 2011). These deficiencies cause a difference in the harvest yields or sometimes in a more severe case, total loss of the crops. Even a small amount affects the plant by lowering its ability to withstand the environmental factors, which in turn affects humans because it can decrease the nutritional content of the food we eat (Grusak 2001). [Anna's Final Manuscript Artifact July 2017].

Anna used the sources that she used to help her construct her argument effectively by citing findings from these primary research articles. I further explored how Anna used sources in order to understand how she gauged credibility when picking her sources. Anna described not using Internet websites or random sources off of Google because they might not be credible.

Anna: I mean I would not pick something from just Google that somebody wrote or a blog or something.

R: Why not?

Anna: Because anybody could write anything on the Internet

R: Fair enough, so what makes an article credible?

Anna: See, it is so easy to think about, yeah you go to the library website, and you have those authors, and whatever, but I am trying to think about what would make it. If they did the experiment, if they have the results, if it was peer-reviewed by somebody else, if that experiment was replicated, and they have other sources to support their findings [Anna's Stimulated Recall Interview July 2017].

Here, Anna recognized that it was not enough to be housed in a library or listed on a library website, but rather the article needed to be gauged for credibility based on the merit of the research presented in the primary research article.

2.3.2 Science as Process:

Across all of Anna's interview and artifact data, all four themes (Table 4.1) associated with the *Science as Process* domain emerged. Anna demonstrated difficulty interpreting insignificant data (theme five). One aspect of Theme six: *Students' feedback and revisions were influenced by their own understanding of the experiment, the assignment expectations, and conventions in scientific writing*, was particularly prevalent in Anna's case. For example, Anna drew on her English background to seek out multiple opportunities for feedback from her TA; however, she was unable to give substantial content feedback on Stacey's writing during her think-aloud interview and relied on grammatical and structural feedback. Anna's limited feedback that she provided suggested that she might have had difficulty understanding the experimental design.

Science as Process was the domain that Anna seemed to have the most difficulty with. Unlike with Science as Access where Anna could draw on her previous knowledge from English, she struggles to understand how to understand and interpret her results. For example, Anna seemed uncomfortable addressing major conceptual edits; rather she focused on grammatical and structural editing. Before moving onto the results, I asked Anna if she noticed any conceptual ideas that needed to be addressed.

> R: Before we go onto the results, in the intro and the methods, were there any big picture ideas that you noticed or are you just focusing on grammar right now?
>
> Anna: I am going through structural, and I am going through content too. So, like she is organizing ideas as well as how she is putting her sentences together so that it makes sense [Anna's Think-Aloud Interview July 2017].

Anna was unable to recognize that Stacey's paper could have been better organized to form a more cohesive argument. Anna then identified that she was "not good at identifying scientific conventions." Her admission further suggested that Anna had limited working knowledge of scientific writing conventions and thus, it impacted how she demonstrated science literacy. Even though Anna struggled with identifying scientific concepts in Stacey's writing, she identified her weaknesses and sought out help to address them. Anna reported that she worked closely with her TA to improve her drafts, thus she demonstrated a high level of motivation and effort to understand and develop scientific writing conventions.

As Anna was peer reviewing Stacey's paper, she focused on minor grammatical errors/stylistic as opposed to larger scale issues such as content. This might suggest that Anna has a superficial understanding of the experiment, and furthermore that she has a superficial understanding of the conventions of scientific writing. For example, Anna asked a question about scientific name conventions:

> I do not know the rule with *Brassica rapa* plants is because she put something on mine [TA feedback], I think you are doing it correctly, but there are some rules with the first time that you mention it and the second time, which I think you did to abbreviate and italicize [Anna's Think-Aloud July 2017].

Even though Anna was unsure of the convention, she was could identified what she did not understand and addressed that during her think-aloud peer review interview. Furthermore, Anna recognized that Stacey used the correct format in her paper and thus was able to use that experience as a model and to help clarify her dissonance about that convention. Anna's data suggested that even though she had difficulty applying scientific conventions, specifically scientific writing conventions, she was eager and determined to learn these conventions.

Anna's unfamiliarity with conventions continued into her rough draft. While reviewing the methods Stacey recognized that Anna was missing critical details, Stacey recognizd this because she had the same issue in her rough draft.

> Stacey: The same thing was on mine, but one of the corrections that I got was that I said that a part of the leaf and the TA said to make sure that you said that two hole-punches were used instead of just saying a piece of the leaf.

> Anna: So, it is confusing because I do not know how much detail to put in and sometimes when I talk about how we did this, it is like there is too much detail and then when I put a small portion, we need to mention two hole-punches of leaves [Anna's Think-aloud Interview July 2017].

This was not specific to Anna; determining the amount of detail to incorporate into the methods section is a difficult skill for all introductory writers. The review process was helpful for Anna as she used it to identify and address her dissonance while at the same time; the think-aloud provided her the opportunity to ask questions.

During Anna's was peer review of Stacey's results, she demonstrated dissonance about both: how the analysis was completed and how the results could be used to determine the effect of plant nutrient deficiencies. However, this exchange with Stacey allowed her to gain further clarity about those topics and ask questioned on how to analyze and interpret her experimental data.

> Anna: Then if you have a higher p-value than 0.05 it means that it is statistically different.
>
> Stacey: It means that it is not statistically different, because it needs to be lower than 0.05
>
> Anna: It is not statistically different if it is 0.05, so it must be under that number for this to be statistically significant, okay. So, when you included this, the data from the spectrophotometer was analyzed using average, standard deviation, standard error, and the average chlorophyll concentrations, why are we talking about concentrations again here?

Stacey: Because the concentrations of chlorophyll in the plant corresponds to a healthier plant because it can go through photosynthesis

Anna: So, a higher level of chlorosis means that the plant is healthier?

Stacey: A higher level of chlorophyll concentration does, but it does matter if it is a, b, or carotenoids. I think it is just the different light types.

Anna: The only reason I am asking is, why would this be important to figure out? I did not know these three were measure, and then these are the three averages for chlorophyll, oh ok chlorophyll A, ok.

Stacey: Yeah so, we took the averages for each three

Anna: Ok, that makes sense. I have a tough time doing this because I do not know how to explain what the graphs are, but I get it a little better now with the way that you explained what the photosynthetic pigments were. That would mean that they are as low as the data that was being analyzed as well as the specific pigments [Anna's Think-Aloud Interview July 2017]..

Anna developed her understanding of how her methods that were used were used in order to experimentally determine the effects of nutrient deficiencies in plants. This exchange did not just seem to help her clarify photosynthesis, but also helped her clarify how she should be writing about her results and explaining her figures.

Anna: So, you put your t-test for each one in each paragraph, which is nice because I did not think about that at all. Ok, stomatal density, so you talk about the average, what is the difference between standard deviation and statistical differences?

Stacey: Standard deviation is, I do not know how it is calculated to be completely honest, but the standard error uses the standard deviation divided by the square root of the total number of tests we did and then that is what you use.

Anna: T-test. Yeah, I do not know the standard. It is deviating from something, but I do not know what the standard is [Anna's Think-Aloud Interview July 2017].

Anna had difficulty with the statistical interpretation of the experiment, which was expected because students are not required to complete a statistics course as a pre-requisite to any core Biology curriculum, more specifically, BIOL 115 or BIOL 117. Students in BIOL 117 used Excel to complete their statistical analysis.

At this point, I stepped in to clarify what the standard deviation was.

R: It deviates from the mean. So, it is the distance from the mean on either side of the curve.

Anna: Well, we have never done this experiment before so where would we look for that?

R: Your measurements calculate standard deviation, so you know how you took multiple measurements; it is a complicated formula where you take the mean minus the number you square it.

Anna: But it comes from our data got it [Anna's Stimulated Recall Interview July 2017].

Anna struggled with the analysis, its interpretation, and how that might relate to answering her hypothesis. She self identified these weaknesses and was confident enough to seek out additional help. Anna being a second-degree seeking student may be the reason that Anna sought out additional help whereas other first year students may not feel as confident to do so. Anna again benefitted from the peer review because, she was able to see how another student was presenting their results, thus viewing a model, had the opportunity to critique another paper, and the opportunity to ask questions in order to address her dissonance.

> The hypothesis was not supported by the results, which in my thing you will see that it was supported. Ok, this is saying that 50% of the magnesium would have an extremely high level of chlorosis, the lowest number of stomata, and the lowest concentration of chlorophyll, however, the 50% treatment group had the highest average total chlorophyll.

By working though Stacey's paper, Anna recognized where there were differences between how she interpreted and represented the data versus how Stacey presented her data and interpretation.

2.3.3 Science as Sociopolitical Factor

Because Anna clearly understood the link that her experiment had concerning a sociopolitical topic her data did not include Theme 8: *Students make limited connections/reference to a larger significance of science without direct prompting*. In her paper, Anna describes the effects of plant nutrient deficiencies:

> Scientists have used a visual observation to identify deficiencies, but in order to test for pseudo deficiencies, nutrient stress, or hidden hunger, soil and plant testing are necessary (McCauley 2011). These deficiencies cause a difference in the harvest yields, or sometimes in a more severe case, total loss of the crops. Even a small amount affects the plant by lowering its ability to withstand the environmental factors, which in turn affects

humans because it can decrease the nutritional content of the food we eat (Grusak 2001). [Anna's Final Manuscript Draft July 2017].

Anna recognized that not only can nutrient deficiencies affect crop yields, but it also could impact the nutritional content of the food that we consume. When probed further about how her experimental research related to a more significant societal issue, Anna elaborated further.

> One of the things that we were talking about was magnesium deficiency. They were saying how many people in the world are affected because crops have less yield that is coming about because of it. We understand what the macronutrients are, what the micronutrients are, and what the essentials of a plant are so that people that are making the food for human beings to exist [can identify the deficiencies] and how they can kind of fix those deficiencies [Anna's Stimulated Recall Interview July 2017].

After Anna discussed her entire writing process, I asked Anna how her experiment related to a more significant societal issue in the context of the discussion. Here, Anna added to her previous description of her sociopolitical topic and elaborated on more significant impacts of understanding nutrient deficiencies in plants.

> Plants, in general, need nutrients to grow, and other than food that we need to exist, many farmers, many engineers, and many doctors, even like in different parts of the world, there could be individual plants that could be used for medicine. If we could find a better way to increase the yield, that would be great for them, so it solves a lot of scientific issues, it also solves a lot of humanitarian issues, such as food and all of that around the world and here too. I do not know, but for people that like to garden, to even garden every day, it would be super annoying to wonder why your plants are dying

> so, they can make it better, I know Kroger has a little fertilizer thing, so they can make better products to use for plants [Anna's Stimulated Recall Interview July 2017].

Anna's ability to elaborate even further on societal links to her experiment demonstrated an understanding of the more significant impacts that plant nutrient deficiencies might have apart from agriculture, for example, product development, medicinal qualities, and world hunger.

2.4 Interesting Trends

Anna has a strong desire to understand how to write scientifically. She was able to identify where her weaknesses were and she asked for help and further clarification when she did not understand. During her think aloud peer-review, Anna discussed turning in multiple rough drafts for feedback before submitting the rough draft.

> I think, this is why I turned in my rough draft for more corrections before we turned it in, because the TA said if we needed help, we could get that [Anna's Stimulated Recall Interview July 2017].

Anna showed a high level of motivation to understand the conventions that she does not understand. The act of recognizing and addressing concerns and critiques demonstrated a willingness to learn if given the opportunity as Anna described in her reflections. Anna also attributed a lot her understanding of having the opportunity to talk about the peer-review in real time. In both of her reflections, Anna described how valuable it was to have a conversation about the edits, and how it aided her understanding.

> Having my partner explain the charts and the trends helped me to figure out what I needed to change. Doing it aloud helped because I got a chance to hear about her thought process, as to why she thought a particular sentence needed to be added to a paragraph,

> or why the titles for the bar graphs were not needed. Typically, when papers are edited, you get the edited copy back, and you have to go through the paper and fix the edits, but you do not have the opportunity to hear what the editor is thinking, or why they did what they did. Doing it aloud helped to clarify specific edits [Anna’s Second Metacognitive Reflection July 2017].

Anna further went on and described how the peer review led her to learn while she actively peer-reviewed her partner's paper.

> It forces you to keep the rubric in mind and challenges you to learn as well as you edit, and have a reason for making the changes [Anna’s Second Metacognitive Reflection July 2017]..

For Anna, having the ability to ask questions, and seeing how someone else put their paper together was valuable to her overall science writing process. As seen throughout her writing process, Anna struggled with understanding scientific conventions, but in her final draft, she applied some of the feedback into her final paper to help her meet some of the conventions of scientific writing, an area where she identifies as weak. For example, Anna was able to apply the convention that figures do not have titles on the graph; this was something she and Stacey discussed.

2.5 Case 2 Summary:

Anna's prior background in English provided her an added benefit when entering into the literature. Because of this background, Anna could enter into the literature, interact with primary literature and use it to cite and support facts. Although Anna's argument is weakly developed in her introduction and discussion sections, the literature that she incorporated does lend nicely to supporting her argument. Furthermore, Anna clearly understood and displayed that it is critical to consider all viewpoints in the literature to situate scientific experiments and results. *Science as Access* was one of Anna's strongest domains (Figure 4.3).

Science as Process domain is where Anna struggled the most. Anna described not being familiar with the conventions in scientific writing and that often contributed to her missing critical factors in her paper. Furthermore, Anna had difficulty with the results section in regards to being able to understand her analysis and interpret what those results meant. The peer review process seemed to be beneficial for Anna as she could see how her partner (both in the lab and the peer review think aloud) presented and interpreted her results, and provided a model for Anna. In addition to this, Anna was able to ask questions in order to gain clarity and address her dissonance. Anna's persistence and desire to improve her skills aligned with the *Science as Process* domain indicate that through iteration and feedback, Anna can develop her scientific process skills.

Anna included *Science as a Sociopolitical Factor* in both her written manuscript-style assignment artifact and in her interview. In her written documents, Anna discussed the economic implications of nutrient deficiencies, such as crop loss and decreased crop yields that could lead to decreased crop availability in stores but did not use citations to support her claims.

Finally, in Figure 4.3 below, I offer a representation of Anna's science literacy as it was demonstrated in her data aligned in the conceptual framework of this dissertation study. Within the three domains, I included the themes that were evident across all sources of her data and supported by the excerpts in this case description.

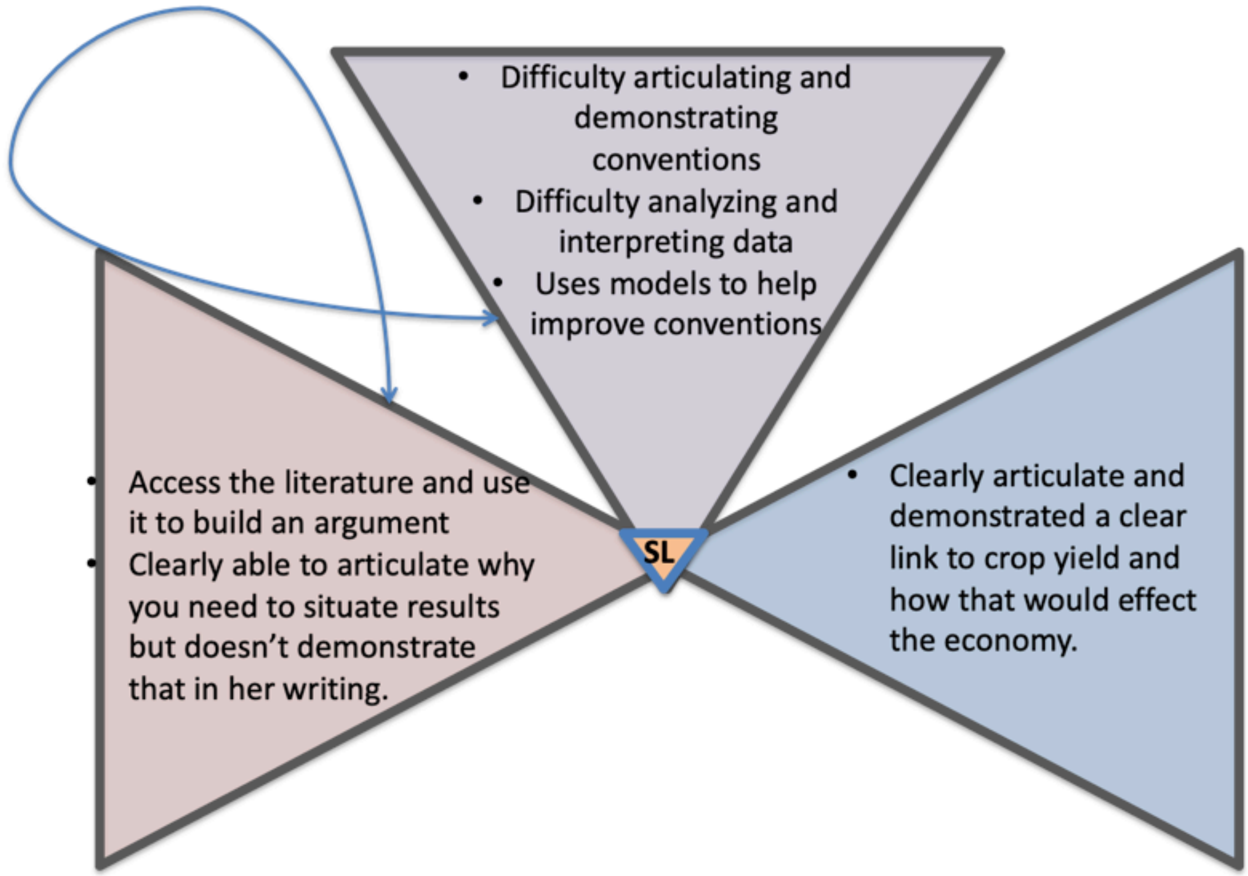

Figure 4.3: Anna's Science Literacy: Summary of Anna's science literacy mapped onto the conceptual framework. Anna was able to draw connections between the literature and her argument developed in the introduction to justify the reasoning for conducting the experimental methods used. While Anna was able to articulate that crop yields were a sociopolitical factor, she described this in terms of plants needing to be healthy, not directly to her experimental design.

Case # 3: Stacey

3.1 Background

Stacey was an undergraduate Immunology and Medical Microbiology major. She completed BIOL 115 with an A. In addition to completing BIOL 115 with an A, Stacey took English 101 as dual credit in high school and she earned an A. While describing her background in science, she described herself as having a good background; however, she described her ability to write in science as moderate. The person who taught and influenced her and her learning was her high school science teacher who also taught her how to write in science. Stacey attributed her everyday experiences with science as her out of school experience and those experiences have shaped her overall learning.

3.2 Stacey's definition and conceptualization of science literacy:

Stacey was presented with an image of the conceptual framework and asked to describe what she interpreted the model. Stacey described an iterative practice:

> The more practice that you have and access to science, the better you are at science literacy." Stacey is suggesting that science literacy is something that develops over time with practice. She also suggests that developing science literacy is at the heart of the framework, that the process starts broad and develops over time, thus relating the framework to the writing process [Stacey's Pre-Interview July 2017].

When asked to define science literacy, Stacey gives a literal definition of science literacy:

> Science literacy is the ability to write and interpret scientific literature or graphs or any visual scientifically [Stacey's Stimulated Recall Interview July 2017].

While Stacey's definition was a literal interpretation of the term science literacy, it also incorporated *Science as Access*, being able to read, write, and interpret scientific literature and *Science as Process*, being able to analyze and interpret graphical representations of data. When asked how her writing process supported science literacy, Stacey described the scientific process:

> I think that it shows science literacy in that you can do the research that shows why your experiment, and then you can go through how and have someone be able to recreate the experiment. Then you can discuss what happened and how this supports your introduction nor how it does not support the research that has happened before [Stacey's Stimulated Recall Interview July 2017].

Here, Stacey described building an argument to justify why you would design and complete an experiment (introduction). She then went on to describe the ability to collect and analyze the data (methods and results) and then have the ability to refute/support your hypothesis and compare and contrasts your results with others (discussion). All of these aspects are indicative the conventions of a manuscript-style writing assignment in science.

3.3 Emergent aspects of Christie's science literacy aligned with the three domains of my conceptual framework

3.3.1 Science as Access

After analysis of all of Stacey's interview and artifact data, all three themes associated with *Science as Access* emerged (Table 4.1). During her reflection on her writing, Stacey noted that she thought the more difficult section to write was the introduction. Stacey's admission that the introduction section was difficult could be attributed to limitations entering into the literature and constructing the argument that she used to shape her introduction.

> I think it is more difficult to write [introductions] than the other sections, because of the research needed writing it [Stacey's Metacognitive Reflection July 2017].

In her final interview, when Stacey was asked about how she wrote her introduction section, she mentioned using the rubric to guide the structure and format of her argument.

> I just used the rubric that was given in the lab manual, and then from there that is where I broke it up into the sections, and then I went through our specific experimental design and used that continuing through the rest of it [Stacey's Stimulated Recall Interview July 2017].

Even though Stacey suggested that she understood the conventions of scientific manuscript style writing consistently throughout her writing process, she did not demonstrate a clear understanding of how the introduction section was structured. Stacey corroborated this when she discussed how the introduction was difficult to write. While Stacey struggled with the organization of her introduction, she described a clear understanding of how to build an argument in her final interview.

> Based off of the hypothesis that we created, we measured our variables from one of the symptoms that we thought the plant was going to show so then because of that, that is what methods we used [Stacey's Stimulated Recall Interview July 2017].

She further demonstrated this when she discussed the logic that she used for her whole paper.

> We started with the hypothesis that we formed from all of the research that we did; magnesium deficient plants would have more chlorosis, less chlorophyll concentration,

> and less stomatal density, and then from that, we tested those variables by using the spectrophotometer and the color scale and the microscope. The results showed that the 100% full magnesium plants did not have a statistical difference from the 50% concentration or the 75% concentration. So the magnesium deficiency was not prevalent in any of the plants, or the symptoms of those were not prevalent. We thought that there were a couple of different reasons that did not happen, and that was maybe that they were not grown for long enough, they were not completely mature plants, or that maybe magnesium deficiency, are only shown if there is some other deficiency in the plant, maybe [Stacey's Stimulated Recall Interview July 2017].

In one instance, as Anna was peer reviewing Stacey's paper, she was unclear about what Stacey meant. Stacey was able to clarify her explanation verbally:

> Anna: Ok, I am not sure what you mean right there.
>
> Stacey: I thought *Brassica rapa* grows quickly so you can see stunted growth, so for example, the chlorosis and the quick time without having to wait for the plant to grow [Stacey's Think-Aloud Interview July 2017].

This quote demonstrated an understanding of the experiment. Stacey used features of the model organism to build her argument, including why it was the ideal organism to perform the study on. Stacey also demonstrated this strong understanding in her final paper where she justified the use and supported her argument using literature.

> *B.rapa* plants are considered one of the best plants to use in the lab setting. They are small and grow rapidly. The plant was developed specifically for plant breeding research. Therefore, it is an ideal candidate for any plant experiment. These plants show

> the effects of deficiency, without considerable growth periods (Tomkins and Williams, 1990). [Stacey's Rough and Final Manuscript Draft July 2017]

While Stacey had a grasp on the conventions of scientific writing and understood the experimental design, Stacey's writing would have benefited from more organization, as to improve her overall argument better that she was developing. In addition, Stacey did not always use citations to support her claims in her argument. For example, in her final paper, Stacey is discussing why an experimental technique could be used.

> Chlorophyll concentration can be found using a spectrophotometer, which measures the absorbance of light at a specific wavelength. More chlorophyll in a plant corresponds to a plant that can absorb more light during photosynthesis [Stacey's Final Paper July 2017].

Stacey did not use a citation to support why she would use the technique, which was interesting because Stacey described being able to find sources to use for this experiment easily.

A lot of primary articles and reputable secondary sources were easy to find [Stacey's Stimulated Recall Interview July 2017].

In her final interview, I asked Stacey how she looked for sources. She described using the university library website, more specifically the biology resources page, and/or Google Scholar. I also asked her if she used her sources in the different sections of the paper.

During her review of Anna's paper, Stacey noticed that Anna needed more background information to support her argument that she developed in her introduction.

> Stacey: I think I would also talk about the magnesium paragraph. There is something about magnesium being a component of chlorophyll or photosynthesis things and maybe talk about that because that supports the reason to do the photosynthetic pigment experiment [Stacey's Think-Aloud Interview July 2017].

Furthermore, Stacey continued to provide Anna feedback on how she would have developed her argument.

> Stacey: I think I would also talk about the magnesium paragraph. There is something about magnesium being a component of chlorophyll or photosynthesis things and maybe talk about that because that supports the reason to do the photosynthetic pigment experiment [Stacey's Think-Aloud Interview July 2017].

3.3.2 Science as Process

Across all of Stacey's data, all four themes associated with *Science as Process* (Table 4.1) emerged. Stacey had a clear understanding of experimental techniques, experimental practices, and scientific writing conventions and used her prior knowledge of science writing to shape her argument structure along with using the rubric as a model. While Stacey had a clear understanding of the conventions, she struggled with her interpretation of insignificant data.

Stacey demonstrated a clear understanding of the conventions of scientific writing. She also clearly demonstrated how to present and interpret quantitative data and results, when they were significant. Stacey did mention having difficulty when it came to qualitative data, an unfamiliar result in STEM laboratories.

> The only trouble that I had with this section was describing the measurement of chlorosis since it was not necessarily quantitative data [Stacey's Stimulated- Recall Interview July 2017].

Stacey identified that she had a limited understanding of how to describe and collect qualitative data, which was expected, as typical introduction laboratory instruction focuses on quantitative data collection and analysis techniques. While this was the standard in the field, Stacey recognized her limitation during the drafting phase of her manuscript. When she reflected on her rough draft, Stacey reported that her methods section needed further clarification.

> The methods section was to add more detail. I need to be more explicit in the procedure and how the experiment was done. For example, instead of saying 'mix small slices of the plant's leaves,' I needed to say 'two hole-punches were taken from a leaf [Stacey's 1st Metacognitive Reflection July 2017].

During her peer review with Anna, Stacey was able to get additional feedback on some specifics that she could add to strengthen and further clarify her methods section.

> Anna: I think this is supposed to be water, I guess nutrients might be a better way than to say soil, but the plant would be unable to absorb them.
>
> Stacey: Yeah, I think your way would be better [Stacey's Think-Aloud Interview July 2017].

Here Anna pointed out to Stacey, that she described the experimental design incorrectly and Stacey could apply Anna's suggestion and described that it would improve her description of her methods. In Stacey's rough draft, she confused the nutrient-free soil, with the nutrient solution that the students use to manipulate nutrient concentrations.

> Anna: I wonder if we have to capitalize phosphorous, I am not sure.
>
> Stacey: I wondered that the whole time I was writing, but I just went for it [Stacey's Think-Aloud Interview July 2017].

This exchange was interesting because both students had the same question/concern; however, neither of them had talked about it or asked for clarification prior to the think-aloud. In the think-aloud both Stacey and Anna proceeded on even with receiving clarification on their question. As previously described, Stacey was confident in her ability to present qualitative data, and therefore was equally confident in her ability to make figures and tables.

> Figures and tables were easy to make on Excel [Stacey's Stimulated Recall Interview July 2017].

Furthermore, Stacey was able to understand how to read her statistical analysis; however, she had difficulty making complete statistical conclusions in her paper, specifically in regards to insignificant data.

Stacey reported all her analytical findings in her final paper, but only determined if a group was significant or not. This suggested that although she has a strong understanding of the analysis, she was unsure about how to fully report and interpret the statistics.

> The values for stomatal density decreased significantly from 100% to 75%, but only slightly decreased from 75% to 50%. The 100% group had an average of 59.33%, 75% was 36.33, and 50% was 35.66 (Figure 3). The standard deviations were 30.59 for 100%, 9.64 for 75%, and 7.20 for 50%. Consistent with the other two groups, the t-tests for

> stomatal density were all greater than 0.05, which means that there was no statistical difference. The t-test values were 0.13 (100% vs. 75%), 0.89 (75% vs. 50%), and 0.12 (100% vs. 50%) [Stacey's Rough and Final Manuscript Draft July 2017].

Here, Stacey made the claim there were differences between groups; however, there were no statistically significant differences between treatment groups. While reviewing Anna's paper, Stacey was quickly able to not only recognize when Anna was incorrectly describing results and the interpretation of those results.

> Right here, where you mention all of these values, I might put that in the results rather than the discussion, and then in the discussion, say this had chlorosis 100% or 75% had the highest or something like that [Stacey's Think-Aloud Interview July 2017].

Stacey drew on her experience and feedback in her draft, to help provide Anna with advise on how to improve her paper; however, Stacey focused on which section of the manuscript the analysis and interpretation of data should be present. Furthermore, she helped Anna by sharing her feedback.

> In my paper, the TA suggested to say something about the future, because, in my rough draft, I put just like in the future, I would change this experiment that we did, to have more time to let the plants grow and stuff like that [Stacey's Think-Aloud Interview July 2017].

This quote demonstrated that Stacey was not only understanding the feedback that she has been given but also that she could apply and transfer that feedback into different contexts. It also supported that Stacey had a strong understanding of the conventions in the field and what information should have been incorporated into each section. Furthermore, Stacey was able to identify gaps in information and structural issues, not just grammatical errors.

When I compared Stacey's advice that she provided to Anna to her writing, while Stacey understood her feedback, in the final draft of her paper, there was no interpretation of her data. When describing her discussion section, Stacey seemed confident in her ability to write and interpret her results.

> I think the discussion was easier than usual to write since the data did not support the hypothesis. It gave much room to interpret why the experiment did not work, and what could be done in the future [Stacey's 1st Metacognitive Reflection July 2017].

Stacey did not interpret her results; instead, she made blanket statements that aspects of the experiments and results were different from other studies, but did not explain as to why this might be. Furthermore, Stacy was missing key rubric points, which suggested that she is writing the paper not to meet the demands of the rubric, but rather writing to communicate her experimental results and meet the scientific writing conventions of the field.

> I needed to add a whole section about the future of the experiment. I also made it more explicit that the hypothesis was not supported, and why this could have happened [Stacey's Think-Aloud Interview July 2017].

Stacey explained this in her stimulated recall interview when she described her writing process when she described how she writes her ideas in bullet form and then develops her paragraphs based on her bullet points that she outlined.

3.3.3 Science as Sociopolitical Factor

Across all of Stacey's interview data and artifact data, she was unable to incorporate a sociopolitical topic into her written artifact. Therefore, the theme: Students make limited connections/references to a larger significance of science without direct prompting emerged, the only theme associated with *Science as a Sociopolitical Factor* domain. This theme emerged because Stacey articulated a sociopolitical topic when prompted even though she did not include it in her written artifact. When asked how her experiment relates to a more significant societal issue, Stacey was able to relate her experiment to agriculture loosely.

> A lot of plants and crops have plant deficiencies, so I think that this experiment shows why and how plants have a specific deficiency [Stacey's Stimulated Recall Interview July 2017] .

When probed further, about a more significant societal issue later in her interview, in the discussion section, Stacey described how deficiencies could impact crop yields.

> Crops could have nutrient deficiencies. I guess based on this experiment, having a deficiency in magnesium, would not necessarily have a problem with crop yields and all of that [Stacey's Stimulated Recall Interview July 2017].

Stacey did introduce the concept of fertilizers adding nutrients to crops; however, she does not connect the sociopolitical topic together with her experimental design and results.

> Fertilizers that contain these minerals are often sprayed on crops to make them grow more efficiently and produce healthier plants overall (Liang et al. 20113) [Stacey's Rough and Final Manuscript Draft July 2017].

This data suggested that Stacey had a limited understanding of how plant nutrients affected the overall plant health and thus demonstrated that she cannot fully articulate the connection between fertilizers, crop yield, and nutrient deficiencies.

3.4 Case 3 Summary:

The weakest domain of Stacey's scientific writing included the skills that consist of the *Science as Access* domain as reported by Stacey. She described that writing her introduction was the most difficult because of the amount of research that you have to do complete it, thus this suggested that entering into the literature is an intimidating task. Stacey also used the rubric to help scaffold the structure of her argument but her introduction was segmented into subsections so there was no cohesive argument formed. While Stacey discussed all of these aspects, her introduction was one of the more developed introductions in the dissertation study as determined by the content that was included in the introduction.

The data supported that Stacey was most successful in executing skills in the *Science as Process* domain. Stacey was able to discuss and apply conventions in scientific writing and identified dissonance that emerged during her think-aloud peer review with Anna. Furthermore, she articulated her analysis and results clearly. One weakness that Stacey had was that she struggled reporting statistics in her scientific writing and making statistical conclusions outside of determining significance based on the p-value.

Lastly, Stacey was loosely able to connect her scientific writing assignment to a more substantial sociopolitical factor by linking fertilizer use to crop yield; however, Stacey was limited in her ability to draw connections linking how fertilizer, magnesium deficiencies, and crop yields are connected.

Finally, in Figure 4.4 below, I offer a representation of Stacey's science literacy as it was demonstrated in her data aligned in the conceptual framework of this dissertation study. Within the three domains, I included the themes that were evident across all sources of her data and supported by the excerpts in this case description.

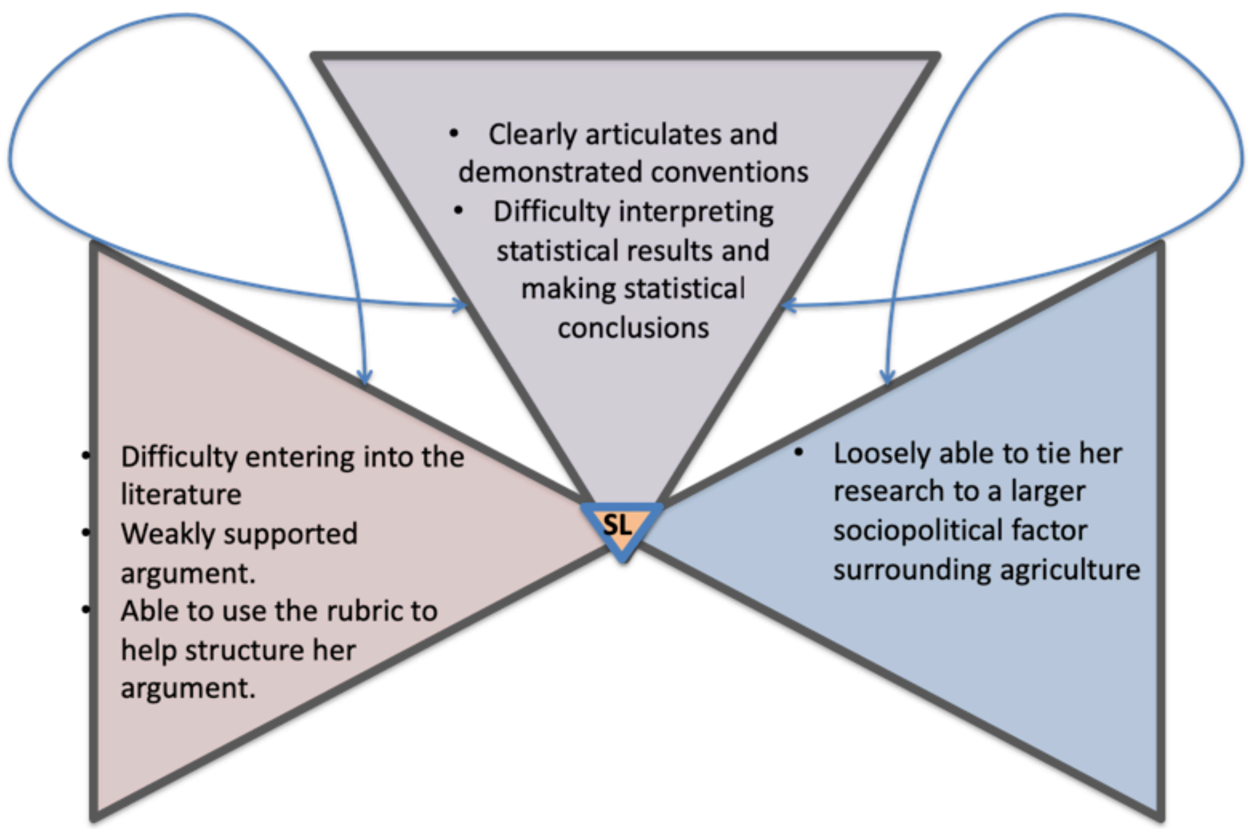

Figure 4.4: Stacey's Science Literacy: Summary of Stacey's science literacy mapped onto the conceptual framework. Stacey was able to draw on the argument developed using literature in the introduction to justify and understand her experimental design and results but was not able to support those arguments using the literature. Furthermore, Stacey was able to talk about a sociopolitical factor, crop yield, but was also to use the results of her experiment to suggest that a magnesium deficiency may not be related to crop yield. The double edged arrows represent a connection established between the two domains that it connects.

Case # 4: Sean

4.1 Background

Sean was an undergraduate biology major. During the screening survey, Sean identified that he had a profound understanding of biology coming into Biology 117 and he successfully completed Biology 115 with an A. Sean attributed his background in science and his learning of science to his father, a high school science teacher. Sean also mentioned that experiential learning with the Boy Scouts had shaped the way that he thinks and learns about the sciences. When asked how confident he regarded his ability to write, he claimed to be relatively confident in his abilities. Prior to starting his undergraduate education, Sean had dual enrollment credits for English 101.

4.2 Sean's definition and conceptualization of science literacy:

When presented with an image of the conceptual framework before completing the assignment, Sean described the framework as:

> A graphical representation of the factors in science literacy. They are [the pieces] big, and essential parts and it kind of reminds me of like deduction [Sean's Pre-Interview July 2017].

In addition to being asked to describe the conceptual framework, Sean was asked to define science literacy; he described it as:

> Being able to understand [Sean's Stimulated Recall Interview July 2017]..

I then probed him to have him clarify what he meant by being able to understand, his response was:

> Understand the science world. Understand when someone says something that may seem outlandish or something to understand to get the point or to understand what they are actually meaning and be able to depict between what is true or what is false [Sean's Stimulated Recall Interview July 2017]..

Sean identified a critical piece of *Science as Access*, credibility. In his definition, he identified being able to critique science as an essential component of science literacy. He also identified that there was a level of deduction; however, he was unable to notice the interconnectedness of the conceptual framework.

4.3 Emergent aspects of Sean's science literacy aligned with the three domains of my conceptual framework

4.3.1 Science as Access:

Across all of Sean's interview data and written artifacts, all three themes associated with *Science as Access* emerged (Table 4.1). Sean had difficulty accessing and using the literature to effectively support his argument that he was constructing. Sean also drew on his prior experiences, such as his experiences in his family garden and the boy scouts to develop his scientific understanding.

Sean described his process for formulating an argument in the introduction of his paper as:

> I start very broadly because you need to get everyone on the same level, because even though it is supposed to be a scientific journal, the people who would read it should have a good understanding, and you want to make sure they do. So, the first paragraph is all just getting caught up to how phosphorous works in a plant, all this you know like

> what nutrient deficiencies look like, and all the broad reasoning. Then you go into more details about what you are going to study, and how it is going to relate back and that is where you use it, where I start to draw more from other resources. You keep going down, I usually put the hypothesis and predicted results near the bottom, because it should be like fresh in their mind as they go to the methods [Sean's Stimulated-Recall Interview July 2017]..

Sean description demonstrated an understanding of the conventional structure of building an argument for scientific writing. However, Sean conflated being concise with developing a well constructed argument:

> I think it is much more scientific to stop your paper before you start adding the "bs." While Sean can identify that scientific writing should be concise, he is unable to write concisely, while developing complex ideas effectively. For example, the introduction to his paper is only one paragraph. His paper demonstrates a lack of clarity and depth. Sean recognizes this when he discusses his methods section and mentions that his methods could be more precise [Sean's Stimulated Recall Interview July 2017].

During his description of how he approaches writing the introduction, Sean mentioned using literature sources to develop his argument. When Sean was asked about how he located those sources, he described his search strategy as using large search engines such as Google Scholar, the university library website, Academic Search Premier, and Web of Science, all common search engines used in STEM. Sean described being comfortable using the search engines:

> If I am looking for phosphorous used in plant cells, I will Google or use the little search bar. I click on the link to full text, and peer-reviewed, and I usually like to do more

> related stuff, so I usually set the year to 1975 [Sean's Stimulated Recall Interview July 2017]..

Sean used some parameters for credibility by the use of peer-reviewed literature; however, when specifically asked about how he gauged credibility, he assumed that the university would not have sources that were not credible.

> If I use the university site, I usually trust that it is relevant and that it is a credible source, because I am not using news websites, or like national geographic, or any secondary sources [Sean's Stimulated Recall Interview July 2017].

Sean displayed that he understood the difference between primary and secondary sources, and credible versus not credible information; however, Sean did not recognize that published sources should also be gauged for credibility. Even though Sean did display the ability to search for sources, he did not always feel confident in his ability to find relevant sources.

> What I did not feel as strong in, is finding enough references that seemed relevant, since the experiment that we are doing is very basic in the scientific world, and the conclusions we are making have been understood for many years [Sean's Stimulated Recall-Interview July 2017].

Sean was then asked how he sourced information from his citations. His first response was the abstract of the paper. He went on to say, that he also used the background information provided in the introduction of the primary research article. Sean attributed using the background information because it was accessible, suggesting a level of scientific discourse necessary to engage in the primary research. Even though he had difficulty engaging with the literature, his attitude towards reading the primary literature may have impacted his performance. This is an example of Theme 9: *Students attitude and perceptions towards their written assignment indirectly influenced their performance.*

> I am not going to read, I hardly ever read the full-text paper, only if it is shorter, because scientific journals are nine pages to ten pages long, and they have the smallest text, and they are all blended together with graphs and stuff that I do not understand yet [Sean's Stimulated- Recall Interview July 2017].

Sean can locate the sources but suggested that he cannot understand the results of the experiments presented in those papers. When he discussed using those sources in his paper, he described using the citations to support facts, sourcing information from the abstract and introductions of the papers.

> All of my references were all for background information, and the beginning of the experiment, so it was easy to get a general understanding of it [Sean's Stimulated Recall Interview July 2017].

Upon reflection on his discussion in his rough draft, Sean further discussed how he used his sources.

> I used previous references to tie it back. In the research that has been done but again, I did not have enough references, mostly because I disagree with digging for references that do not help support our experiment [Sean's 1st Metacognitive Reflection July 2017].

When looking at this in his paper, Sean used one source to support his claim that there should have been differences between treatments, but suggested that there was too much human error, when in fact his results showed significant differences.

> Other research has shown that there should be some differences, but again data collection methods contain much error, and therefore skew the data and make it hard to conclude (Sharpley et al., 2007) [Sean's Rough and Final Manuscript Draft July 2017].

Based on Sean's presented data, there was a clear significant difference in leaf number and plant height, which suggested that Sean did not understand how to interpret his statistical analysis. Further, Sean's use of this citation suggested that he had difficulty incorporating sources.

Lastly, when discussing how, Sean used his sources to end his introduction and ultimately formulate his hypothesis. Sean discussed not generating his hypothesis based on previous research and understanding of the experiment but instead based on his beliefs.

> Most of my hypothesis came from what I truly believed, in my opinion, when you o a hypothesis if you use too many references from other places, it is too influenced by others that it is not your work, but obviously a lot of the information that I used to form it, I got from background information [Sean's Stimulated Recall Interview July 2017].

Sean contradicted himself here. He claimed that his hypothesis was based on his beliefs and not literature, but he described a process where he built his beliefs based on the literature/background information that he has read. The latter would suggest that he is using the literature to build an argument, whereas the former would suggest that he had difficulty constructing an argument using the primary literature.

4.3.2 Science as Process

Across all of Sean's interview and artifact data, three of the four theme associated with *Science as Process* (Table 4.1) emerged. The theme that did not emerge from Sean's data was

Students display a strong understanding of traditional and scientific processes such as generating hypotheses, completing experiments, and following models. This was clearly demonstrated above where Sean described building his argument based on his beliefs.

Sean discusses his process for writing his methods section by working through the conventions for that section. For example:

> You almost have to balance on the line of enough detail to make it replicable, but not too much to make it wordy. One thing I feel I could have done better was to clarify certain areas of the experiment [Sean's Stimulated- Recall Interview July 2017].

Here, Sean demonstrated that he understood the conventions needed to write concisely, but also recognized that he struggled to complete that. During Sean's think-aloud interview, I prompted him to look at the rubric to make sure that he was addressing all the methods that needed to be addressed because he was missing critical methods, such as the analysis. Sean responded that he did not often use the rubric to guide his writing:

> I do not always even look at the rubric normally, because I flip back to the procedure because the methods normally, even on the rubric is tell me what you did…I was going to end it there, but then it was talking about how you have to tell them about how you did your data analysis, like how you got your data, not just show how you did your experiment. So, I had to talk about pigment analysis and stomatal density there. [Sean's Think-Aloud Interview July 2017].

Even though Sean discussed the rubrics as guidelines, he also seemed to suggest that he had a strong working knowledge of the methods section; however, he lacked the most critical part to replicate the results of the experiment, the analysis section. Furthermore, Sean was unable to separate methods from analytical techniques:

> R: What other analyses did you do?
>
> S: I missed one, I forgot that there was plant height, and there was the number of leaves [Sean's Think-Aloud Interview July 2017].

Here, Sean discussed the methods he used to collect the data, as opposed to how he analyzed his data; for example, he did not discuss using student t-tests to analyze group differences.

In his reflection, Sean mentioned that writing his results and discussion went well. Sean represented his data in a graphical representation; however, while he was able to create graphs, he was missing critical data from the experiment, including his pigment analysis; in his case an indicator of magnesium deficiency. He attributed the missing data to his inability to find the data on the Excel sheet.

> We were supposed to have bar graphs for chlorophyll, and she showed us how to do it, and I think she had it somewhere, but in the Excel sheet, she sent us it was a tab that you have to scroll over. I put a little thing in my discussion section saying that I just kind of b.s. 'd it, mostly because I did not know what happened to it like I just put the pigment analysis is omitted for unseen reasons, I did not even know what happened to it [Sean's Think-Aloud Interview July 2017]..

What was interesting about this is he did not reach out to his TA to inquire about the data, nor did he correct this in his final draft of his paper. Sean chose not to incorporate the edit from the think-aloud interview even though he recognized that it was a necessary part of the paper.

At the end of his think aloud, Sean discussed this:

> I did not change anything, because she only took off three points even without having the pigment because we told her about it but I could not find it, and half of the class had a problem with it…I did not put the pigment data back in because I only lost three points, so I was not worried about it. I know this sounds bad, but I am like a student that if it is good, then I am not going to change it even for easy classes. Like I am pretty sure that I have an A in the lab so like 3 points, I am not worried about them [Sean's Think-Aloud Interview July 2017].

In his second reflection, Sean reiterates that he did not make any changes to the final paper because he did not lose any significant points on his draft for not including it.

> I did not make any changes because I understand that a few points on one paper are not going to alter my grade in the lab significantly [Sean's 2nd Metacognitive Reflection July 2017].

When Sean discussed his data analysis, he discussed being confident in his ability to conduct t-tests and p-values. In the same phrase, he also described having difficulty calculating and adding error bars to his graphs.

> A bar graph, here with the average stomatal densities and the error bars, which I feel like I calculated wrong because they do not look right, but I am honestly no wizard on the computer. Which is something that I could get better at? P-values here, which I know how to calculate, but I think she gave us the p-values for this one so the t-test she already did [Sean's Think-Aloud Interview July 2017].

Sean expressed that he was confident in his ability to calculate p-values; however, he was not able to accurately interpret p-values for significance. For example, in his discussion he stated:

> This experiment seems to be inconclusive because the data seemed to be too variable to be sure of an outcome [Sean's Rough and Final Draft of Manuscript July 2017].

This statement supported that Sean is had difficulty interpreting his statistical analysis. There were apparent statistical differences, as reported by Sean in his report for both his leaf count and plant height data.

4.3.3 Science as Sociopolitical Factor

Across his interview data and his written artifacts, the theme associated with *Science as a Sociopolitical Factor* domain, *Students make limited connections/references to a larger significance of science without direct prompting* did not emerge. Sean was easily able to identify a sociopolitical factor related to his experiment during his stimulated interview. Sean identified the link to agriculture in the discussion section of his paper.

> Also, if this hypothesis is supported, then how could it be applying to real-world problems, like in agriculture [Sean's Rough Manuscript Draft and Final Manuscript Draft July 2017].

Although Sean does not demonstrate a clear connection from his experiment to agriculture in his paper, he further elaborates on the connection in his final interview.

> I talked about using it for agricultural since we are talking about plant deficiencies. I grew up in a smaller town, and we have a big garden, we always wondered why our corn sometimes did terribly, and we found it was a mixture before phosphorous, and I believe calcium deficiencies in the soil. It could be fixed by doing more crop rotations in the soil because some of them put back more phosphorous. Agriculture is the most critical connection, probably in medical fields, or anything with plants. You can go from

> biofuels to medicine to food, so it is pretty relevant [Sean's Stimulated Recall Interview July 2017].

Sean was able to draw on his personal experiences to make the broader connections between his plant nutrition experiment to the sociopolitical topic of agriculture. Sean also elaborated to think of other applications, like biofuels, and medicine, which further demonstrates that he understands the broader significance of basic research.

4.4 Interesting Trends

Even though Sean and I went through and completed the think-aloud peer review, and Sean was able to recognize the issues in his writing and self-identify where he was struggled with his writing, he only made minor edits to his draft, which included eliminating underlined spaces. Sean recognized that his writing was not at an undergraduate level:

> I do not know, the intro did not seem like I was a college student at all while I was reading it, and also, I used like an 8-word sentence, which is not normal unless it is…I also need to add the pigment analysis data, which again would add a lot more to the report [Sean's Think-Aloud Interview July 2017].

Sean was very confident about his ability to write scientifically and his ability to conduct experiments. He displayed a high level of confidence in his writing. In his Stimulated Recall interview, Sean discussed his style of writing:

> I am more into the short and concise kind of writing; I feel once you get wordy that it is not as good, in my opinion. I feel like I get docked points for that, but that is the way I believe in writing, and that is the same with my references, I do not believe in just sprinkling in random references [Sean's Stimulated Recall Interview July 2017].

Sean's overconfidence in his writing hindered his ability to develop his ideas, and formulate strong arguments using the literature.

4.5 Case 4 Summary:

Science as Access was a category that Sean displayed a weak understanding of. He could identify the necessity of credible science and primary literature and set parameters to search for peer-reviewed research; however, he assumed that published science is credible and did not gauge credibility based on scientific merit. Furthermore, Sean misuses primary literature when citing, only utilizing information from the abstract and introduction, and thus had difficulty formulating hypotheses. Sean's perceptions and attitude towards reading primary literature and how he believed that science should be impacted his *Science as Access* domain.

Sean was more confident about his ability in regards to *Science as a Process*. He was confident talking about the necessary conventions but often did not translate that understanding nor demonstrate those conventions in his writing. For example, a convention I n scientific writing is to build a hypothesis using prior scientific findings; Sean believed that hypotheses should be self-generated, which demonstrated dissonance surrounding hypothesis generation. Sean also struggled with writing his analysis and interpreting his statistics, including missing data from the experiment. Sean was aware of this during the rough draft of this missing information but chose not to include the data because he was not penalized in the rough draft for it. This suggested that Sean recognized his limitations within the *Science as Process* domain but was unwilling to address them as they were of little consequence to him at the moment as indicated by his discussion of awarded points for the assignment.

Lastly, Sean used experiential learning to articulate his sociopolitical connection. Sean reflected on an experience his parents had on their family farm regarding a magnesium nutrient deficiency. Sean was further able to articulate that multiple connections could be made including medical depending on the crop, agriculturally, biofuels, and economically. This demonstrated that Sean was able to not only draw on his personal experiences to understand his experiment, but was able to draw connections between his experiment and experimental findings with a larger sociopolitical topic, and clear indication of *Science as a Sociopolitical Topic* domain.

Finally, in Figure 4.5 below, I offer a representation of Sean's science literacy as it was demonstrated in her data aligned in the conceptual framework of this dissertation study. Within the three domains, I included the themes that were evident across all sources of her data and supported by the excerpts in this case description.

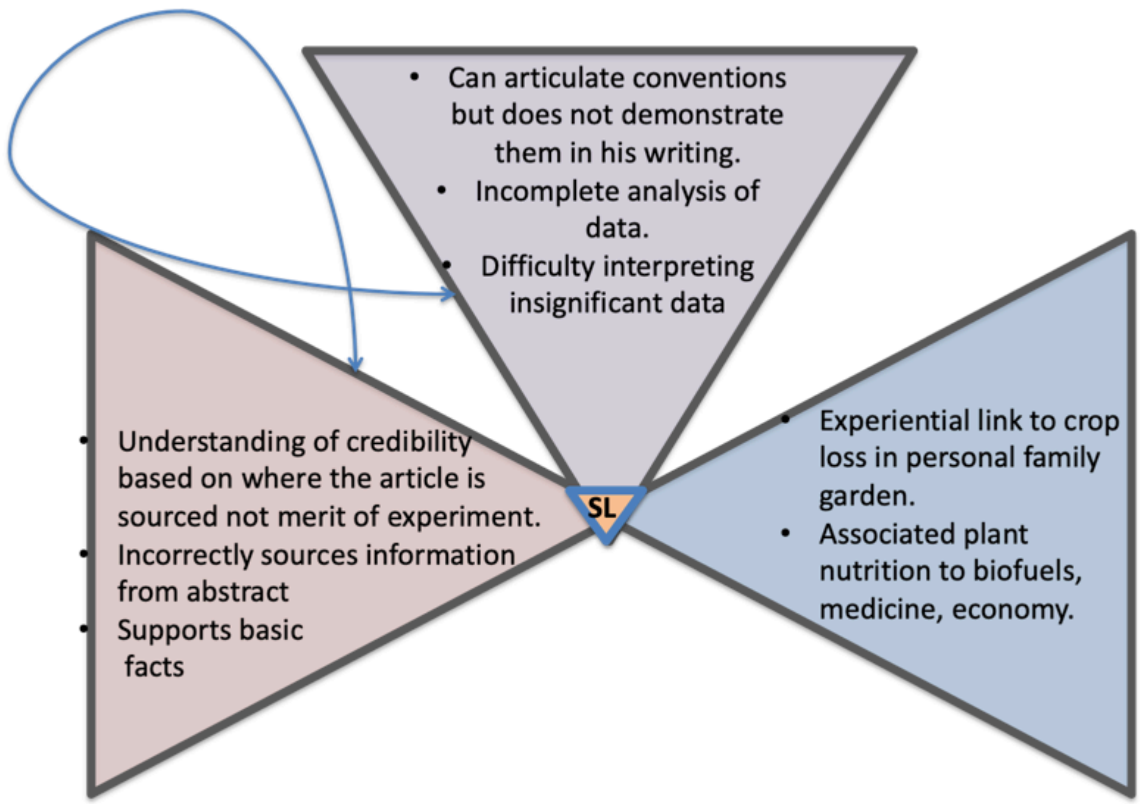

Figure 4.5: Sean's Science Literacy: Summary of Sean's science literacy mapped onto the conceptual framework. Sean's hypothesis was developed using the literature based on potential deficiency symptoms that may have been seen; thus, he demonstrated a connection between the Science as Access and Science as Process domains represented by the double edge arrows. While Sean did describe a sociopolitical factor, he drew on experiential learning as opposed to his results or the literature.

Case # 5: Jen

5.1 Background

Jen was an undergraduate who intended to major in pre-pharmacy. During the screening survey, Jen identified that she had a fair background in science. In addition to having a fair background in science, Jen also believed that she was a decent scientific writer. When asked about who influenced her scientific learning, Jen attributed her science learning to her professors and the way that they engage with the material while teaching. Here Jen described a model that she used to influence her science learning. Jen was successful in both the pre-requisite for BIOL 117, BIOL 115 and her ENGL 101 courses earning an A in both courses.

5.2 Jen's definition and conceptualization of scientific literacy:

In Jen's description of the conceptual framework, she can described each piece of the framework and deduce what it could mean. Jen realized that there was interconnectedness between all three of the domains, and those domains related to science literacy [Jen's Pre-Interview July 2017]. Jen was also asked to define science literacy, after she had completed writing her full paper, at the start of her final interview.

> Being able to write scientifically, and I feel like that is different, in the way of like I do not know like with English, or storytelling that is straighter to the point, facts, that is what I got out of it [Jen's Stimulated Recall Interview July 2017].

She was then asked how her writing showed science literacy:

> It shows science literacy because it is talking about a specific report and its structure in the correct format for science literacy, and it is not like too detailed or anything [Jen's Stimulated Recall Interview July 2017].

After going through her full manuscript-style writing assignment, I then asked Jen to define science literacy again. She responded by saying:

> I guess science literacy is just writing in science [Jen's Stimulated Recall Interview July 2017].

Here, Jen described science literacy as, content specific literacy, and being able to write according to discipline-specific norms.

5.3 Emergent aspects of Jen's science literacy aligned with the three domains of my conceptual framework

5.3.1 Science as Access

Across all of Jen's interview data and written artifact data, all three themes associated with *Science as Access* (Table 4.1) emerged from her data. Jen, like her peers had difficulty entering into the literature, reading the literature, using it to construct and argument, and drew on her prior experience to help guide her scientific writing process. Jen suggested that the introduction was the easiest part of the paper to write.

> I would say the introduction was the easiest to write. The rubric was a great guide in helping me to complete the introduction. The hardest part of the introduction was finding some primary sources to incorporate into it [Jen's 1st Metacognitive Reflection July 2017].

Jen was comfortable developing the introduction given that she had a model to follow. Jen described viewing and using models as a way that she constructs her science learning. However, she still recognized that she had difficulty incorporating sources. This data suggested that Jen might have benefitted from more scaffolding in the rubric.

> Sources on the WVU library site, and then I also looked at some on Google for scholarly articles [Jen's Stimulated Recall Interview July 2017].

When asked how she evaluated her sources for credibility, Jen mentioned that she used the authors, and what journal the article was published in.

> I look at the authors; I look at who is publishing it, and what scientific journal it was in [Jen's Stimulated Recall Interview July 2017].

To further understand how Jen was evaluating the scientific journal for credibility, I asked her to elaborate on the topic.

> I have never really looked to see if the journal is credible, I assume, if it is in the WVU library, then I assume that it is credible and that it is ok to use. If it is Google, I am not sure, I guess [Jen's Stimulated Recall Interview July 2017].

Jen assumed that just because a source is published, that the source is credible. This assumption was expected with first-year students because they are unfamiliar with gauging methods, and data for credibility, due to a lack of discourse within the field.

Jen was also asked how she uses sources in order to cite information, in her papers.

> I first look at the abstract to see if I could find anything, and then I look at the results section, or as the end discussion part, [I look there] to see as the conclusion of the experiment, and to see if they go, what they were looking for, and I could compare their discussion results to my discussion results [Jen's Stimulated Recall Interview July 2017].

Jen understood that she should be using sources to support her experimental conclusions, and mentioned using other experimental results in order to situate her experimental conclusions in the current literature, by comparing and contrasting the results to formulate her argument.

Jen also recognized that this comparison occurs within the discussion section of the scientific writing manuscript-style assignment. While Jen recognized how to use the sources in the discussion of her results, she did not seem as clear on how to use sources in the introduction to build an argument.

> I used my sources for specific definitions and stuff in the introduction. I guess to show that it is real because, if I say it myself, then it might not be as credible, so I need to prove it with credibility [Jen's Stimulated Recall Interview July 2017]. .

I expected this from a first-year student who was learning to use and incorporate primary literature; this statement suggested that Jen had difficulty accessing the literature necessary to build effective arguments. Jen's use of sources in her introduction corroborates this.

5.3.2 Science as Process

Across her interview data and written artifacts, all four themes associated with the *Science as Process* domain (Table 4.1) emerged from Jen's data. Jen articulated an understanding of conventions but often had difficulty translating them into her writing. In addition, Jen had difficulty interpreting insignificant statistical results and only made revisions based on her TA feedback not incorporating peer feedback.

Jen was asked to describe her process for writing the methods section of her manusctipt-style writing assignment and she attributed her ability to write the methods to the following the lab manual as a model.

> I mainly use the lab manual for support, to help write the methods sections because, it is a lot to remember, and I know there were specific numbers that we wanted which, I would not remember from the top of my head [Jen's Stimulated Recall Interview July 2017].

During her stimulated recall interview, Jen was asked if anything was surprising about her results. Jen was surprised that her experimental results were not all significant; thus, this suggested that Jen did not consider that her results might not be significantly different.

> Jen: I guess the p-value because they were, most of the data was insignificant, and I do not know, I guess I was not expecting most of the data to be insignificant.
>
> R: What were you expecting?
>
> Jen: I was expecting the data because whenever the data is insignificant, that means it does not support your hypothesis right [Jen's Stimulated Recall Interview July 2017].

Jen recognized that her statistics, more specifically her p-values, must be significant to signify a difference between treatment groups; however, she did not understand how to navigate and interpret insignificant statistical data. Jen further demonstrated that she had difficulty analyzing her results. Jen predicted that there would be differences between the complete nutrient treatment group versus the nutrient deficient treatment group.

> I predicted that the plant, with full nutrients and no deficiency, would have the greatest height and the most amount of health leaves. Which was like true observational wise, but statistically I guess it just was not [Jen's Stimulated Recall Interview July 2017].

Jen's logic was complete here biologically, a plant with limited phosphorous, would not develop new tissues, and thus would have stunted growth; however, when trying to determine why her experimental results did not support that fact, Jen was unable to think about the biological reasons she had previously discussed; instead she determined her results were insignificant due to human error.

> You look at your experimental error and what you did wrong in the lab to see what you can fix [Jen's Stimulated Recall Interview July 2017].

Jen conflated experimental error and "human error." For example, an experimental error could be a limited sample size, or a confounding variable, as opposed to a person not measuring correctly.

When Jen discussed how she wrote her discussion section, Jen again described relying on the rubric as a model to help guide her scientific writing. This section was the least scaffolded section and demanded a higher level of critical thinking, combined with access to the literature.

> The discussion was difficult because I had to like draw conclusions from the graphs, and then talk about that, also, find some articles, like comparing data or similar results but that is how I went about writing the discussion [Jen's Stimulated Recall Interview July 2017].

When asked why the discussion section was difficult for Jen, she replied

> It was, and it required more thought, with the introduction, you look up information and go about it, same with the methods and results, it is what you get, but the discussion is like pulling it all together, which requires a lot more I would say [Jen's Stimulated Recall Interview July 2017].

When asked how she synthesized her entire paper in the discussion, for example drawing connections between the introduction, methods, and results, Jen described how she wrote the discussion section.

> You talk about whether your objective was met, which was in the introduction, from I guess the methods and your results together. It is much explanation from your previous parts of the report, and then while you explain, you know you compare data or contrast data with something else [Jen's Stimulated Recall Interview July 2017].

Jen continued on to say, that she structured her discussion to align with the rubric. Jen's relied heavily on the structure of the rubric in order to write her paper.

To probe further, I asked Jen if she did not have a rubric, how would she set up her discussion. This was done to understand if she understood the structure of the section. Interestingly, Jen mentioned using another discussion section as a model.

> I would probably search for other discussions and see how their structure was used as a comparison to go off [Jen's Stimulated Recall Interview July 2017].

While this might have suggested that Jen may not have explicitly understood how to write a discussion section unaided, she did acknowledge where she could find resources on how to help her structure a discussion, i.e. additional models. Furthermore, this suggested that she used the rubric as a structural model.

Jen, like many students, found the results section to be the most challenging section to complete for her final paper, but again, Jen relied on the rubric to help write her results section.

> In the results section, I used the rubric. I looked at my tables and graphs and just explained it in the results section [Jen's Stimulated Recall Interview July 2017].

The rubric for the results again had limited scaffolding and asks for a description of trends, data, and statistical analysis (Figure XX). Figures and Tables had their own section of the rubric; this section had more scaffolding than the results portion (Appendix G). Jen attributed her difficulty writing this section, of the manuscript-style writing assignment, to her limited understanding of how to create graphs and tables.

> The results section was the hardest and most challenging section. I had a tough time creating the tables and the graphs, and I still feel like I did it incorrectly [Jen's Stimulated Recall Interview July 2017].

Jen further went on to describe that if she had a better working knowledge of how to create graphs, this section would have been easier to write. During instruction, one lab was dedicated to analyzing sample data presented in the same format as the student's actual data is presented; including how to calculate the statistics and creating graphs. This is an additional model for analysis that students could follow.

When examining Jen's graphs that she presented in both her rough draft and final paper, her graphs were correctly constructed. The only change from the rough draft to the final draft was the inclusion of more descriptive figure captions. In her final interview, while discussing her data, she suggests that her main struggle came from interpreting her data.

> The discussion section was not too difficult, I had trouble interpreting my data, and I think I need to work on that [Jen's Stimulated Recall Interview July 2017].

While Jen recognized that she had limitations with interpreting her data, she made no changes from her rough draft to her final draft, regarding interpreting her data. Furthermore, in her results section of her draft, she did not include any statistical results (required per the rubric). For her final draft, she did include the statistical results, but they were presented in the table, which is not the convention in scientific writing. Furthermore, her statistical results presented did not provide conclusions to the statistical tests.

During her interview process, Jen described the usefulness of the peer review, and think aloud interview. She described working with a partner, as a useful task that highlighted mistakes that she was unaware that she is making.

> The revision process helped shine a light on some mistakes I would never have caught on my own [Jen's 2nd Metacognitive Reflection July 2017]. .

This statement suggested that Jen did not necessarily revise her writing on her own, but instead addresses concerns raised by her TA.

> I mostly used comments from my TA, so I did not use many comments from the peer review [Jen's 2nd Metacognitive Reflection July 2017]. .

During her last reflection, Jen reflected on how useful the think-aloud was in helping her identify weak points in her scientific writing, but that she did not take them into account; instead, she focused solely on the feedback that was provided to her by her instructor.

> When editing my paper to turn in, I mostly used comments from my [instructor], so I did not use many comments from my peer review. Though I did not take any suggestions from my peer review, it was still beneficial in seeing a different perspective in my paper and highlighted points for future lab reports I may write [Jen's 2nd Metacognitive Reflection July 2017].

Jen may have benefitted by taking some of her peer feedback. Her partner, Tim, articulated how she could describe her results while incorporating her statistics, which is something that she was missing in her final paper. The adherence to instructor expectations was consistent with her reliance on the rubric for writing her manuscript-style writing assignment and suggested that she was writing for a grade as opposed to building science literacy.

5.3.3 Science as Sociopolitical Factor

Across all of her interview data and written artifacts, Jen was unable to make a connection between her experiment and a sociopolitical topic; therefore, the theme associated with *Science as a Sociopolitical Factor* domain (Table 4.1) emerged in Jen's data. Jen was able to discuss a sociopolitical topic after being prompted twice during her stimulated recall interview, which suggested that Jen might have associated the sociopolitical topic with the discussion section of her manuscript-style writing assignment.

Initially, Jen had difficulty with connecting her small experiment with a broader societal issue. Specifically, when she was asked how her writing assignment connected to a larger societal issue while discussing her introduction, a section where broader significance is addressed, Jen's response was:

> I do not see any problems, sorry [Jen's Stimulated Recall Interview July 2017]. .

However, when Jen discussed the same question after going through her entire paper, more specifically, in the discussion section, Jen was able to identify a sophisticated link to agriculture:

> A larger societal issue may be with plant nutrient deficiencies [could be] ground depletion or overharvesting…avoid that and instead, help crops and farms [Jen's Stimulated Recall Interview July 2017].

Jen appeared to have an understanding that overharvesting crops and plants could disrupt nutrient contents in soil, a concept that was not explicitly discussed in the class. While Jen did indicate that she understood a connection between her experiment and a larger societal issue, Jen made no direct link to a broader significance in her draft or final written assignment.

5.4 Interesting Trends

Throughout her participation in the study, Jen was the only participant to make repeated, explicit reference to how time-consuming the authentic manuscript-style writing assignment process was. Specifically, she mentioned it repeatedly in her first reflection (3 times in 1 page of writing), and then again in her final interview where we discussed her writing process as a whole. Why this was interesting, was because of the way that she described her overall writing process. When Jen discussed how she wrote her paper, Jen discussed using the rubric as a structural skeleton.

> First, I look at the rubric and see what specific things it wants, and what it is looking for, and then I go off that. I expand and add more to it to make it better and to make it flow more [Jen's Stimulated Recall Interview July 2017].

In her final paper, Jen's paper did follow the structure of the rubric and addressed the rubric prompt without elaboration. For example, for the introduction of the paper, the rubric asked the student to include background information for deficiencies:

> Deficiencies, general and your specific deficiency: Why are they important? What happens if a plant lacks an essential nutrient? What functions could be affected or disrupted? What are the typical characteristics of deficiencies? What causes deficiencies? How/Why do you artificially create deficiencies in the lab? (Appendix G).

In this excerpt of her introduction from her final draft, Jen addressed what deficiencies are in general, and the specific nutrient deficiency being studied in her experiment.

> It is important to study plant deficiency because, these nutrients are necessary for the life of plants, and knowing more about it can help with better farming and plant growth in general. If a plant lacks an essential nutrient, then it will not grow correctly because

> the nutrient is directly involved in plant nutrition. The plant will not be able to complete its life cycle, and no other nutrient can perform the same function as the one that the plant is lacking for its deficiency. The essential nutrient we are going to be examining in this experiment is phosphorus, and how a phosphorus deficient plants function. Plants take up P as phosphate (Pi) from the soil solution. Since little Pi is available in most soils, P fertilizers are applied to crops, (Hammond et al. 2004). Phosphorus is a component of ATP nucleic acids, phospholipids, and several coenzymes. It is important for a plant cell division and the development of new tissues. Typically seen, is stunted growth in young plants, and dark green leaves with necrosis in phosphorus-deficient plants. Phosphorus deficiency can be caused by excessive rainfall, which can cause phosphorus to leach out of the soil, and cold weather can also cause a phosphorus deficiency. Acidic soil can also make it difficult for plants to take up phosphorus, even if the soil does not lack the nutrient. In the lab, we will artificially create a phosphorus deficiency in plants, by merely giving it soil that lacks the nutrients. We are doing this study to examine what a phosphorus deficient plant looks like [Jen's Rough and Final Manuscript Draft July 2017].

While Jen did follow the structure rubric, she did not seem to elaborate on the topics, while citing literature as support. Furthermore, Jen described this section as the easiest and least "time-consuming" section to write.

The connection between time and ease of writing coincided to the amount of detail provided on the rubric. For example, the introduction portion of the rubric was the most detailed portion.

> The rubric was an excellent guide in helping me to complete the introduction. The hardest part of the introduction was finding some primary sources to incorporate into it [Jen's Metacognitive Reflection July 2017].

Jen seemed to benefit from the added scaffolding, and the structural support of the rubric; however, when that structure was eliminated or sparse (Appendix G), the task of writing became overwhelming and time-consuming. For example, the results section is sparse on scaffolding, and this was the hardest section for Jen to write.

> The [results] was the hardest and most difficult section. I had a tough time creating the tables, and graphs, and I still feel like I did it incorrectly. Then trying to talk about the data added more to the load. This section was long and time-consuming only because of the graphs; if it were not for my lack of knowledge on graphs, it would have been easier [Jen's Stimulated Recall Interview July 2017].

Overall, based on Jen's description and discussion of her final paper, it seemed that she benefitted from more scaffolding on the rubric, as opposed to less. For example, in her reflection, the introduction was the only section of the paper that she did not refer to as time-consuming. The less guidance and scaffolding she had, the more frustrated she seemed to become during the writing process, thus linking that section to being time-consuming.

5.5 Case 5 Summary:

Jen was able to identify her search criteria for finding primary and secondary sources using search engines. When deciding on credibility, Jen assumed that primary literature that was published was credible as opposed gauging the article based on the scientific merit. While Jen may superficially gauge an article for credibility, she claimed that she can source information from the results and conclusion of the experiment. Additionally, Jen used her rubric to help structure her overall argument in the introduction. This suggested that Jen could discuss the conventions of accessing, gauging, and incorporating scientific literature; however, she demonstrated difficulty translating these skills to her scientific manuscript-style writing assignment. Her ability to discuss the skills necessary to meet the demands of the *Science as Access* domain indicates that there was room to develop and move toward science literacy.

Jen was not as successful in the *Science as Process* domain. She often struggled with her analysis and interpretation of her analysis. This difficulty was due to her insignificant data; however, Jen was correctly able to determine the statistical significance of her analytic tests. Because Jen used the rubric as her guide for structuring her entire paper, she was able to follow prescribed conventions in scientific manuscript-style writing assignment.

Jen loosely identified a sociopolitical link when asked during her interview and drew a connection between overharvesting and crop loss concerning plant nutrition but was not able to elaborate on that. She did not address any broader significance in her manuscript rough draft or final draft.

Finally, in Figure 4.6 below, I offer a representation of Jen's science literacy as it was demonstrated in her data aligned in the conceptual framework of this dissertation study. Within the three domains, I included the themes that were evident across all sources of her data and supported by the excerpts in this case description.

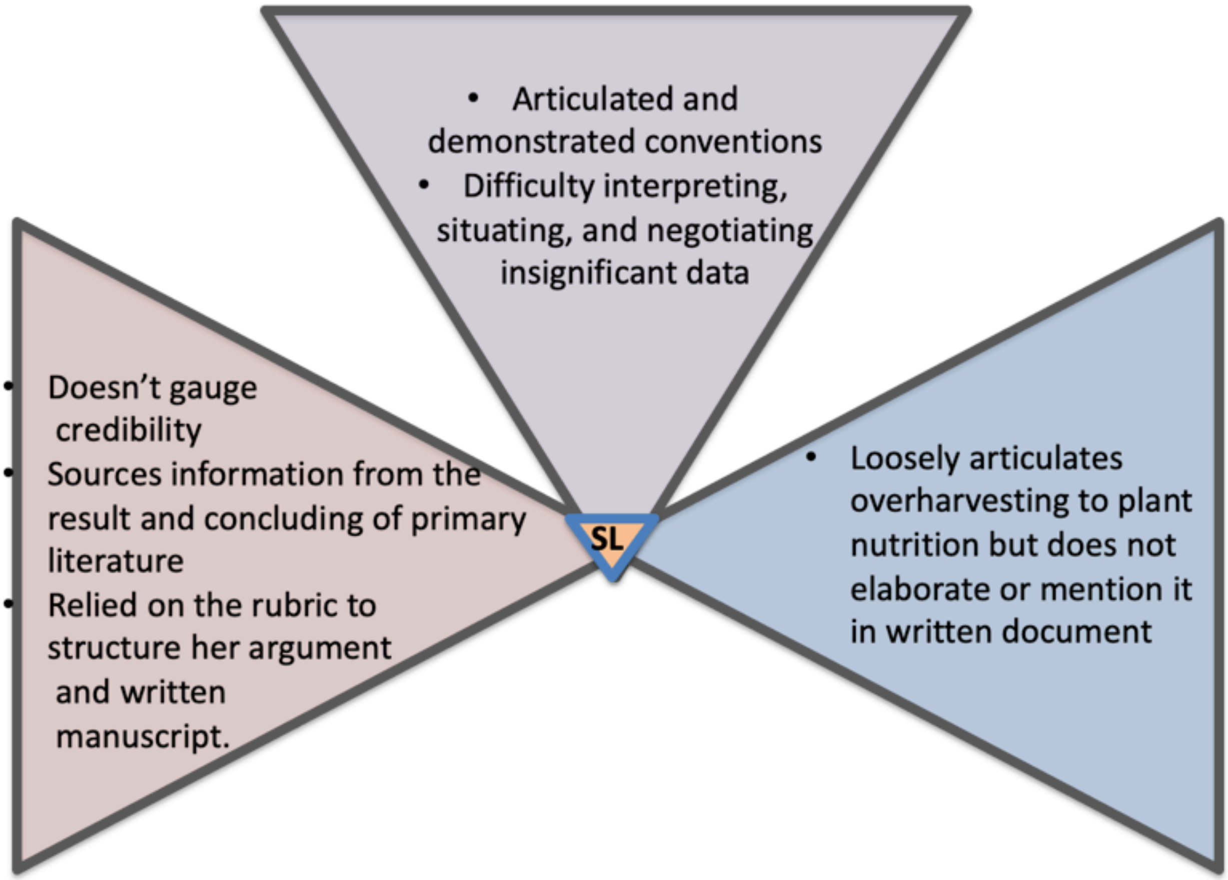

Figure 4.6: Jen's Science Literacy: Summary of Jen's science literacy mapped onto the conceptual framework. Jen was unable to discuss any connections between her argument, experimental design, results, and broader significance. In addition, Jen was unable to neither draw connections between the three domains nor discuss how each domain informed each other. Jen heavily relied on the rubric to construct her manuscript.

Case # 6: Tim

6.1 Background

Tim was an undergraduate who intended to major in biology. During his screening survey, Tim discussed having an extensive science background and he based this on the high number of STEM courses that he took in secondary school. Tim gauged himself as being adequate when it comes to writing in science and he claimed to be confident in his ability to write. Furthermore, he claimed to have possessed adequate content knowledge while suggesting that even though he was adequate, there was always room for improvement. Tim also described himself as a driven individual who was a self-motivated learner, who was determined to be successful. During the interviewing process, Tim discussed his previous engineering major as an influence on his scientific writing. Tim was successful in both the pre-requisite for BIOL 117 and his ENGL 101 courses and earned an A in both courses.

6.2 Tim's definition and conceptualization of scientific literacy:

Tim was presented with an image of the conceptual framework before writing his paper and was asked to describe the figure. He described the figure as:

> …each piece largely is its own thing, as in it is not like the science as a process, an example being that is, I think it can be used as a process yet, it can interconnect with say like science as a sociopolitical factor…[Tim's Pre-Interview July 2017].

Tim noticed that each piece was independent, but also connected and that those pieces could influence another domain.

Tim was also asked to define science literacy:

> My definition of science literacy would be, still being able to interpret and analyze data, being able to know and pull information from scientific studies, and articles stating that you can accurately describe, or figure out the point that they are trying to get across in the article, and just knowing that the scientific ins and out of the scientific process [Tim's Stimulated Recall Interview July 2017].

Tim was able to identify Science as Access, and Science as Process in his definition of science literacy. Interestingly, his definition did not align with his writing process. For example, Tim mentioned being able to use and interpret primary literature, although he mentioned in his interview that he wished he could use more secondary sources, such as books and the sources that Tim utilized in his paper were secondary sources.

6.3 Emergent aspects of Tim's science literacy aligned with the three domains of my conceptual framework

6.3.1 Science as Access:

Across his interview data and written artifacts all three themes associated with Science as Access (Table 4.1) emerged. Tim had difficulty entering into the literature and using the literature to develop a well-supported argument. Tim also relied on his prior experiences to help him negotiate and enter into the discourse of the science field and especially into the discourse of scientific manuscript-style writing.

Tim referenced the scientific process and related that process to a task he did in his everyday life, cooking. He compared Science as Access to a recipe that one would use in cooking. He then further described how one might "fix a recipe" which could parallel building on existing literature in a new experiment.

While Tim incorporated literature into his rough draft, he used the literature to support facts, rather than using the literature to create and develop an argument, as to why he should be studying the effects of magnesium on plants. For example, Tim used the literature in his rough draft, to support that plants obtain nutrients from the underground water:

> These are primarily found in the water underground and absorbed via the plant's roots (Palladin 2010) [Tim's Rough and Final Manuscript Draft July 2017].

What was interesting about this citation is that the information being cited was incorrect; plants do not get their nutrients through the underground water, but rather from the parent soil in which the plant's roots are located. Furthermore, Tim used a book to gain this information rather than a primary article. While secondary sources were acceptable sources, this suggested that Tim was not comfortable accessing the primary literature. Likewise, Tim did not support information when he should have. For example:

> It is important to study nutrient deficiencies because it is a very real, worldly problem. Plants can be affected by deficiencies in many regions of the world, thus creating great shortages of plant-based products [Tim's Rough and Final Manuscript Draft July 2017].

A lack of citation here suggested that Tim struggled with not only citing the information correctly but also distinguishing when he should use a citation or not within the context of his argument. After looking at the references that Tim used for this paper, I noticed that he was using all secondary sources. This is a precise instance where Tim was not comfortable entering into the primary literature and lacked the ability to develop an argument for this paper based on primary scientific literature.

During his reflection of the rough draft, Tim mentioned that he thought finding sources took a great deal of time.

> I felt that finding articles and books to source information from took the most time [Tim's 1st Metacognitive Reflection July 2017].

Completing a literature review, and finding support in the literature, is a daunting task that even takes seasoned experts time to complete. While I agreed that it would take a long time, Tim did not use primary literature, which suggested that while he may have spent much time looking into the literature, he did not use any primary research articles. This suggested that Tim lacked access to the literature in both terms of physical and conceptually; this was supported by his lack of citing primary research articles.

During the think-aloud protocol/revision process, Tim recognized the proper use of a citation from the primary literature in Jen's (his peer review partner) paper as the reviewer:

> …is a really good citation you have here, with the effects of fungi and how especially the mycorrhizae kind of spread the plant's root coverage, you might want to say that, and go out and say that this expands the root, the plant's root coverage without actually having to grow more [Tim's Think-Aloud Interview July 2017]..

When Jen (Tim's peer reviewer during the think aloud) was reviewing Tim's paper, she did not have much feedback to provide to Tim even though Tim asked for feedback on individual sections. For example, Tim asked Jen:

> Do you see any jumps in my train of thought through the writing, like I am going on one thing, and then I go to the next detail and stuff like that, where I go back to three details ago? [Tim's Think-Aloud Interview July 2017].

Tim recognized that he struggled with building an argument and preserving the flow of ideas throughout his writing. Jen also recognized that Tim did not compare his results to the literature. Tim attempted to justify not comparing the data by stating that he did not have any significant data:

> With all of our [data] being insignificant, it was hard for me to compare data because none of it meant anything. I could say the sky is blue, and the sky is blue in France, but I guess if it is not the same I can't really, I do not feel like I can write much about that like tell me if I am wrong [Tim's Think-Aloud Interview July 2017].

This discrepancy between significant data and using the literature to compare and contrast his findings was interesting and spoke to the interconnectedness between the *Science as Process* and *Science as Access*. By not having a strong understanding of the analysis and results, Tim was unable to use the literature to help interpret and situate his results.

When specifically asked, his process for a literature search, Tim mentioned the use of online databases through the university library. He also mentioned that he refrained from using websites, due to credibility issues:

> Usually, I look at online databases. I used WVU libraries pretty extensively. It is, probably not the best thing, but I have trained myself not to use websites, even what you would consider being credible websites. I think it is because websites, regardless sometimes can be a little iffy on their information, apart from a true documented and peer-reviewed report. I wish I could pick from books and things from the library, but sometimes, especially with these kinds of studies, you do not have that kind of time to go pick out books at the library. Because I feel like some of the information that I want

> to use, would be much better laid out, detailed in a book, than as background in someone else's article [Tim's Stimulated Recall Interview July 2017].

Here, Tim acknowledged that he found information from books, more accessible than in the primary literature. What was interesting about this is that he wished that he could use the information from books, when in fact his citations for his rough and final draft, all came from books. He further discussed how he read primary literature, which suggested that he had an approach to reading the literature, but his approach is limited, which was typical of first-year students. For example:

> Usually depends on what I am looking to source, sometimes, if I use the abstract to definitely tell what it is about to kind of figure out, what whether to use a source I want to use, their introduction background, if there is some information that they found that I haven't, that I feel would be nice to add, just more general background or something that actually does support my theory behind the experiment. Sometime, I will look at the methods, the results, and conclusion to see if there is something I am missing, nothing too specific that I can really put my mind on, but I usually try to look all over, but the abstract is what I use to determine whether I may even use the article at all [Tim's Stimulated Recall Interview July 2017].

Tim suggested that he used the abstract to select the article; this was consistent with how seasoned researchers would sift through large amounts of data. Tim also claimed to use the literature to cite facts and background information, which suggested that he is only using the introduction to cite information, as opposed to the results of the study, as one would typically do to comprehend the article.

While Tim has claimed to know how to use primary literature, and that he incorporated primary literature, Tim's writing process suggested that he has a limited working knowledge of incorporating primary literature into an argument. Instead, Tim relied on background information from secondary book sources to cite biological facts.

6.3.2 Science as Process:

Across his interview data and artifact data, all four themes associated with the *Science as Process* domain (Table 4.1) emerged from Tim's data. Tim had difficulty with interpreting and analyzing data both significant and insignificant; however, he was clearly able to articulate scientific conventions and he drew on his previous experiences for peer-review. Lastly, Tim wrote for the demands of the assignment.

During the pre-interview, Tim again referenced the scientific process and related that process to a task he did in his everyday life, cooking. He likened scientific experimentation by experimenting with different ingredients.

> …you can experiment with different flavors and what does this do to that dish…the same thing, as I do not know, like what new [thing] in our lab, what new trend deficiency will do to this plant and what effects will it have [Tim's Stimulated Recall Interview July 2017].

While there was a loose connection here, Tim did not recognize that the decisions made in the lab were based on prior experimental results and logical next steps, thus supporting the idea that Tim had a disconnect between the *Science as Access* and *Science as Process* domains.

When drafting his methods section, Tim demonstrated a lack of understanding of the protocol and the associated reasoning behind the method. This was demonstrated in his language and level of detail used. For example, Tim could not correctly use biological terms, and substituted them with common language; *"a paper slip"* was used in place of a wick. There was also a large amount of unnecessary detail, and critical details that were omitted that would suggest that there was a misinterpretation of the conventions of scientific writing. For example, the methods for stomatal density are not reproducible as they are currently written:

> Leaf samples were also taken and analyzed for stomatal density. A slide was prepared by placing a grid with 1mm x 1mm spaces. Leaves were selected from six plants and coated with a thin coat of nail polish. These were then cut, placed on the grid, and covered with clear tape. The visible stoma within one grid square was counted [Tim's Rough and Final Manuscript Drafts July 2017].

Tim also appeared to be aware of his weaknesses in the writing process; when reflecting on the methods section, Tim thought that he was reporting the proper amount of detail but then goes on to say that he could write more detail. Furthermore, Tim excluded critical methods, such as the analysis portion of the methods section.

This omission demonstrated that Tim may not be following the rubric to write his manuscript as it was a method that was required; and also suggested that Tim might not understand the analysis portion in enough detail to be able to write about how it was completed.

The results of the study were expected to be presented as a bar graph, which represented the means and standard error of the data set. Each dependent variable was represented on a separate graph. The students were then asked to calculate student t-tests on their data. When Tim represented his data, the graphs were constructed correctly; however, Tim discussed fitting a curve to his data, which was not applicable given the data was not continuous data. For example:

> The graph indicates a sharp increase in the plants as their levels of Mg absorption were reduced but appeared to off around 50% of the required dosage. The curve seemed to end at a value of 10. Each treatment group ranged in its chlorosis appearance and could be subject to further analysis [Tim's Rough and Final Manuscript Draft July 2017].

The description of the data suggested that Tim drew on his prior knowledge and experience as an engineering student and transferred those data analysis skills to his current experiment. The current analysis was attempting to present trends within the data; however, his analysis was incorrect, and a curve could not be fit to this data. Furthermore, Tim did not include his statistical analysis in his written manuscript.

In his metacognitive reflection, Tim reported having very little confidence in writing about the results and analysis. He goes on to say that *"the way I write requires some interpretation, or explanation to preserve the flow of the work."* Tim's description of how he wrote his results suggested that he is unsure about the way to report results and analysis, following the conventions of the field. It also suggested that Tim was not familiar with the differences between making a conclusion based on data and interpreting what that data means. This misunderstanding was further supported in the think-aloud when explicitly asked about t-test and p-values:

> R: When you read primary literature, do you ever see p-values presented in tables?
>
> Tim: Usually not.
>
> R: Where do you typically see them?

Tim: They are the numbers from our analysis, aren't they?

R: They have a meaning to them; how did you determine if something was significant or not?

Tim: If it was below 0.05

R: Ok, so that p-value tells you if it is significant or not, it is a probability. Does that go in your results or your discussion section?

Jen: Results? [Tim's Think-Aloud Interview July 2017].

The interaction during the think-aloud suggested that Tim had a clear understanding of what p-values are and where you might find them conventionally in primary literature; however, given his limited understanding of the analysis, Tim seemed to be struggling with incorporating the results of that analysis. Later, when Tim reflected on his discussion section, he reiterated his lack of confidence, and then goes on to describe what should be present in the results section:

> I enjoy interpreting the data and explaining data trends. Sometimes, I feel I miss some details in the explanations and possibly overlook data trends, and barely touch on any explanation. Otherwise, I feel that I can explain the data and interpret any of its underlying meaning [Tim's Stimulated Recall Interview July 2017].

Trends in the data were reported in the results section. Tim's rough draft showed very little interpretation of the data in the discussion section:

> Regarding the effects of magnesium deficiency that were seen in the experiment, specifically the pigment concentration, the deficiency was seen to increase the concentrations slightly. This may be the plant's response to the stress it experienced [Tim's Rough and Final Manuscript Draft July 2017].

According to the results presented, there were no significant differences between the pigments, and thus this interpretation would be flawed. There is also no evidence provided via the literature to corroborate that this may be the issue. Jen addressed this during the review. Jen asks Tim if he compared his data with the literature (a requirement of the paper):

> Jen: Did you compare your data with other data?
>
> Tim: With all of ours being insignificant, it was hard for me to compare data because none of it meant anything [Tim's Think-Aloud Interview July 2017].

Tim was not only having issues here analyzing the data, but he was also having difficulty deriving meaning and how that data might be supported in other studies. During his second reflection, this issue persisted for Tim because he was still unable to address his interpretation; however, now he conflated the interpretation of the statistical data with data that goes into the methods section. Examples of this confusion are present in the final draft of the paper as well.

Although there were changes made to the final draft, most of the changes were simple grammatical changes or adding information that was missing, for example, the statistical analysis method, and a paragraph of p-values for one dependent variable, with no statistical conclusion made. Tim kept his discussion of the curves being fit to their data and did not incorporate any comparison between literature; instead, he presented more facts about magnesium.

When explicitly asked about his writing process for the methods, Tim responded by mentioning the field conventions that he followed:

> I just tried to be as specific as possible when pertaining to the um; the steps are written in the lab manual and um I kept it all in the past tense and without steps or bullet points

> just the general structure of a methods section. Broke up the analysis and taking the data for the chlorosis, and the photoreceptors, and the stomata, and um just tried to keep the values correct and detailed enough to where it could be replicable [Tim's Stimulated Recall Interview July 2017].

Even though Tim spent much time focusing on conventions for the methods section and appropriately identified the conventions and he drew the connection that the methods he was using were to collect quantitative data for analysis, thus drawing on the scientific method.

Tim never referred to the statistical analysis when discussing the result section. He did, however, mention it when asked if anything was surprising about his results where he reported that none of the results being significant was unexpected. Tim then went on to attribute the insignificant data to the level of class:

> Yeah, it was surprising, but then again being a general biology class, I can sometimes see where people may not care if you get what I am saying. Also, I also think carelessness sometimes provide issues with the experiment, and it results not being significant [Tim's Stimulated Recall Interview July 2017].

This instance again suggested that Tim was having difficulty interpreting his data that turned out to be insignificant. Tim attempted to downplay his insignificant data as not "real data" therefore minimizing its importance. He also discussed this in the think aloud interview, where he referred to the lab as not a "serious lab." This mischaracterization of the lab suggested that Tim was not perceiving the experiment, or writing as authentic; instead, as an assignment that needs to be completed for a grade.

6.3.3 Science as a Sociopolitical Factor:

Across Tim's interview data and written artifacts, the only theme associated with *Science as a Sociopolitical Factor* (Table 4.1) emerged from Tim's data. Tim was able to verbally discuss a sociopolitical topic; however, he did not include a sociopolitical topic into his written manuscript-style writing assignment. Tim mentions in his rough draft the importance of understanding plant nutrition, and how that could affect products.

> It is important to study nutrient deficiencies because it is a very real worldly problem. Plants can be affected by deficiencies in many regions of the world, thus creating great shortages of plant-based products [Tim's Rough Manuscript Rough July 2017].

While there was an indirect mention of a potential economic problem, Tim did not explicitly make the connection.

When Tim was explicitly asked how his writing assignment demonstrated a connection to a larger societal issue, Tim mentioned a direct link to agricultural, and he also referenced that he discussed it in his paper. Interestingly, when asked the same question while discussing the discussion, Tim responded differently:

> My final assignment didn't really connect to a larger societal issue, just because I focused too much on the issue of not having statistically significant data, because I know we wouldn't be studying these kinds of things if there weren't an actual issue with the deficiency, otherwise magnesium we know as a trace element perhaps, just because that being a macronutrient it has severe effects on plants and if the data supported the hypothesis, that there is going to statistically significant differences between the treatment groups, I would definitely write more about the issues with agriculture, and

> more society, other than trying to give suggestion on why the data wasn't correct and would need to be fixed [Tim's Stimulated Recall Interview July 2017].

Consistent with the writing assignment, Tim was still paralyzed by his data not being significant, that he could no longer see the broader importance of his research, and how it might have contributed to the field. During his final interview, Tim was then asked how his writing assignment demonstrated science literacy. Tim responded:

> I mean, as I discussed it, I can see where my science literacy may be a little lacking in certain areas, such as research and in writing, what I feel may be a little more critical details, I feel I can see myself more of the problem that I described, and I do feel that I still am scientifically literate, it is just that the way my thought process kind of moves and works, it sometimes prevents me from writing to my full potential [Tim's Stimulated Recall Interview July 2017].

This suggested that Tim believed that he has a full understanding of all three domains, and the interactions occurring between the three domains. This claim, however, was not supported in Tim's writing.

6.4 Interesting Trends:

Tim discussed his writing process as limiting his ability to demonstrate his science literacy. During his final interview, Tim was describing his struggles with writing the discussion section and was asked what would help him personally to address those struggles. Tim's answer was not instructionally related; instead, he referenced the amount of time he had:

> I don't really know for me, sometimes it's just a matter of time, not having enough time to really sit down and be able to think about it, with all kinds of different things going on

> around me, and I know summer classes aren't too much of an issue, especially during the school year at all, all the classes piling on top of each other, sometimes you have to sacrifice quality for time [Tim’s Stimulated Recall Interview July 2017].

It would be expected that time would be more of an issue during the summer courses since they are accelerated. This also suggested that the student was willing to put effort into the assignment to produce quality work but was limited by the time constraints. Tim suggested that this often added pressure on him to sacrifice quality in his writing in order to meet deadlines.

Another trend that was prevalent in Tim's story was his lack of confidence in what he was writing. While there were instances where Tim reported being confident, such as in the methods section, this seemed to be a measure of overconfidence, because his methods contained many conventional errors. Tim's writing seemed to corroborate his lack of confidence. His weakest sections of the paper were the introduction, results, and discussion. Tim reported that he was not confident about any one of these sections at multiple points through the study. While Tim lacked confidence about his sections, he still claimed to be scientifically literate.

6.5 Case 6 Summary:

While Tim was able to have a conversation about primary literature and correctly identify primary literature and where to use it during his think aloud, Tim did not incorporate primary literature into his manuscript; instead, Tim relied on secondary sources in books, a format that he found more accessible than primary literature sources. Due to this inability to access primary literature and enter into the discourse of scientific writing, Tim's argument as to why you should study magnesium in plants was weakly supported, and often the facts he used to support information was poorly paraphrased.

Tim discussed specific conventions in scientific writing and how it would be demonstrated in the manuscript-style writing assignment with ease. Tim's greatest struggle was analyzing and interpreting his data. In the methods section, Tim was unable to clearly describe his analytic approach, suggesting that he may not have a firm understanding of the methods. This inability to talk about the analysis trickled into how he reported and interpreted his results often attributing them to not real data and not having any meaning because the statistical test was insignificant.

When asked about his writing was connected to a broader significance, Tim again did not feel like his data justified talking about larger significance; however, in the introduction when asked the same question, Tim recognized that nutrient deficiencies could lead to crop loss and lower crop yields thus having an economic effect.

Finally, in Figure 4.7 below, I offer a representation of Tim’s science literacy as it was demonstrated in her data aligned in the conceptual framework of this dissertation study. Within the three domains, I included the themes that were evident across all sources of her data and supported by the excerpts in this case description.

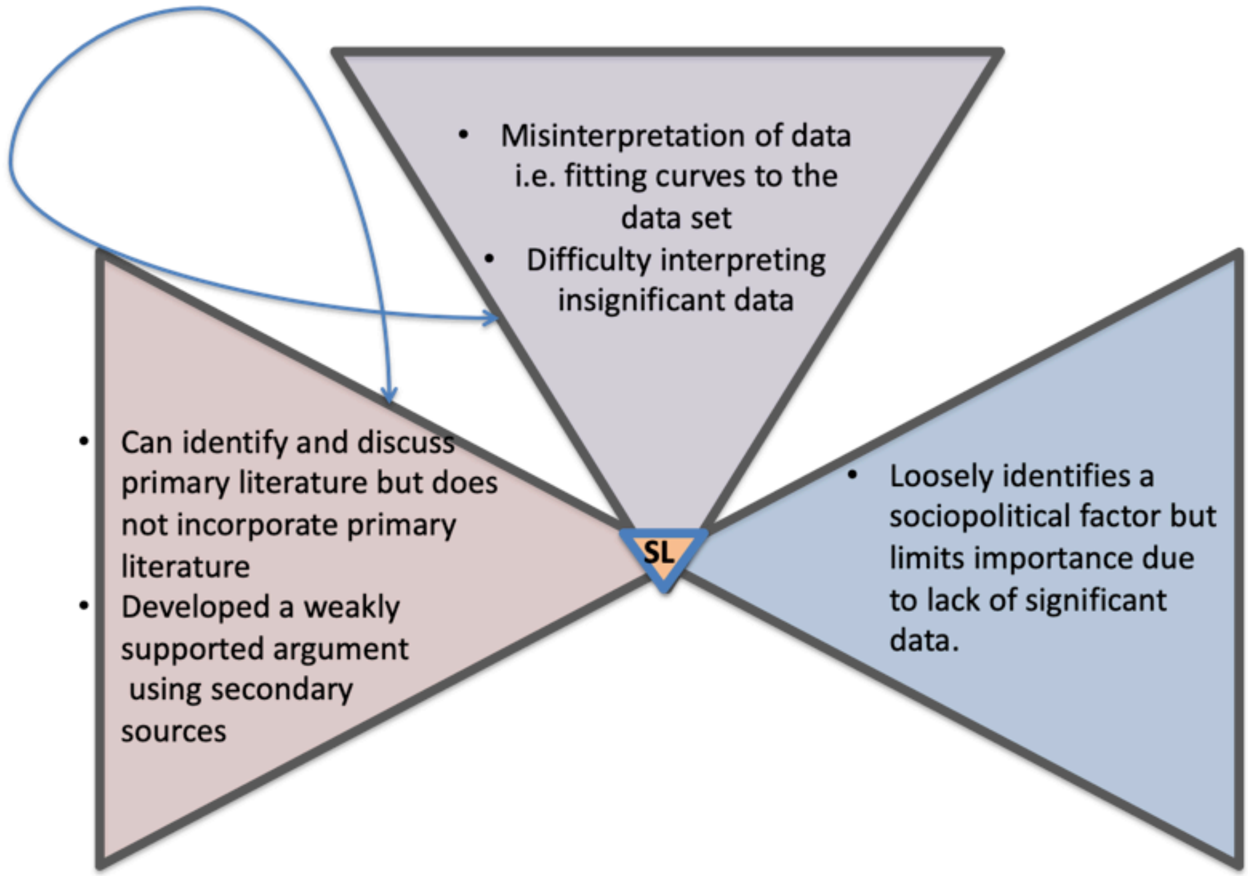

Figure 4.7: Tim's Science Literacy: Summary of Tim's science literacy mapped onto the conceptual framework. Tim developed a connection between the primary/secondary literature on deficiency symptoms and how they were tested in the experiment. Tim drew connections between *Science as Access* and *Science as Process* as indicated by a double arrow.

Case # 7: Joey

7.1 Background

Joey was an undergraduate Chemistry major and he completed BIOL 115, the pre-requisite for BIOL 117 with an A. Joey also completed ENGL 101 and earned a B for his overall final grade. Joey described that he had an excellent chemistry-based background with some foundation of biology. He also described himself as having a good level of confidence in his ability to write scientifically, specifically when writing manuscript-style laboratory reports. Joey's love of science was the most influential way that he learned science and described it as being self-motivated. Lastly, Joey did not attribute a single out of school experience that has shaped how he has learned science; however, he does describe how learning through trial and error has shaped how he learns science.

7.2 Joey's definition and conceptualization of science literacy:

Joey was presented an image of the conceptual framework and asked to describe what it meant to him. He described the following interpretation:

> First would be the Science as a Process, like writing the paper, and Science as an Access is people reading your paper, and like proofreading and then the last one I would say is more of an internet-based thing, and anyone can see it for additional research and all three of those links for science literacy [Joey's Pre-Interview July 2017].

Joey identified specific aspects of the *Science as Access* and *Science as Process* domains including peer-review, accessing the scientific writing and the actual act of scientific writing. He also accurately linked process skills like writing with the proper domain as defined by the conceptual framework.

> I feel like just based on lab we more or less go over science as a process just basically writing it do not explore science, the other two or we like, we have to use additional sources in our papers, so more or less science as an access kind of thing [Joey's Pre-Interview July 2017].

Joey misinterpreted what was meant by *Science as a Sociopolitical Factor*. Joey was also asked to define science literacy.

> Knowing the process of how to write a scientific paper or for chemistry so say biology or any science, but in my opinion, there are different forms of it. For biology we write in CSE format for citations and chemistry we write in MLA. Building an understanding of the process where there are different steps into doing it, like the scientific method there are steps for that. You can base that to start writing a lab or a lab report and just understanding the process of scientific writing where there is an introduction, methods, results, and discussion. Basing that on an experiment where you are writing a scientific paper you are more or less going to have all those parts included in your paper which I feel like that builds scientific literacy [Joey's Stimulated Recall Interview July 2017].

At first, Joey defined science literacy from a technical standpoint; however, while he was describing it from a technical, scientific writing aspect, his definition still incorporated *Science as Access* in regards to citation format and *Science as Process* in regards to the scientific method. Like in his description of the conceptual framework, Joey's definition of science literacy did not include *Science as a Sociopolitical Factor*.

7.3 Emergent aspects of Joey's science literacy aligned with the three domains of my conceptual framework

7.3.1 Science as Access:

Across all of his interview data and written artifacts, all three themes associated with the *Science as Access* domain (Table 4.1) emerged. Like his peers, Joey had difficulty entering into the literature and using the literature to construct a well-supported argument. Additionally, Joey relied on his prior knowledge to help him navigate the discourse of science manuscript-style writing.

Through his series of interviews and artifacts Joey spent a great deal of time discussing how he developed his arguments both in the introduction and the discussion sections of his manuscript drafts. Joey's process for developing his arguments revolves around his methods section of his paper. He describes writing the methods first and using that format to shape his overall argument in his introduction.

> I always write the methods first because just reading the methods you could write bullet points down onto what you want to write in your introduction, and that is where I start with my introduction. I was getting some bullet points down and talk about them and then the stuff we learned in class with the hourglass method where you start broad and get more specific and then on a general broadness with like your hypothesis [Joey's Stimulated Recall Interview July 2017].

Joey furthers went on to discuss how his understanding of the methods not only shaped the introduction but also allowed him to predict his expected results of the experiment.

> When writing my methods, topics can be easily discussed, and that is what I write about in my introduction. The methods should also tell you what your results should look like [Joey's Stimulated Recall Interview July 2017].

In addition to discussing how he approached his argument construction in the introduction, he also recognized that the argument he had developed in the introduction had a prescribed structure. Joey described how building the argument was about gathering and presenting all of the information necessary to provide the proper background.

> I feel like gathering all the information together is more, I would say like building a puzzle, you get a source here, a source here, and after all the information you can read

> it over and with the information gathered you could build a hypothesis [Joey's Stimulated Recall Interview July 2017].

Because the introduction requires the combination of many sources and the massive amount of scientific research available, Joey found the introduction a particularly challenging section to write.

> The introduction, when I try to write introductions, it is the hardest part based on the fact that ideas can go on and on [Joey's 1st Metacognitive Reflection July 2017].

During his think-aloud protocol interview, Joey's peer reviewer, David, noticed that although his argument was based on his methods section, Joey did not include background or justification on why he could use those methods to test his hypothesis.

> Joey: You think I should have like a paragraph explaining all of the methods?
>
> David: Maybe not a paragraph but just a little bit before that, like stomatal density as more stomata is present the healthier the plant is and then with like the pigments like more pigmentation the healthier the plant is so that it does not come out of anywhere [Joey's Think-Aloud Interview July 2017].

Joey had a gap in logic in the argument that he developed. He mentioned this in his reflection that he liked to tie all of the sections together using the methods as his starting point, but did not include the justifications for the methods that he used when constructing his argument in the introduction. This suggested that although Joey was using his methods to model other sections of his paper, he was not able to connect how the literature and those methods were connected. Joey also used the same logic when he discussed how he built his argument in the discussion section.

> For the discussion, I try to bring it all together and link the intro (based on his methods) with the discussion with my results [Joey's 1st Metacognitive Reflection July 2017].

Joey described his process for developing his argument in the discussion as the following:

> I started with the hypothesis. It is when I am restating the hypothesis in the discussion; it is restating my info in the introduction, based on my introduction. And I just start with the hypothesis then I start expanding on the results, why I saw these trends, what I think happened and then linking up the discussion with the literature or my results to the literature and I just feel like in general, the whole discussion can go back to the methods because the methods tell you what your solving for and your discussion your basically explaining what you saw [Joey's Stimulated Recall Interview July 2017].

Joey relied on the methods to not only frame the structure of his argument in the introduction but also again in the discussion section. Joey stated that he is used the methods to help frame his argument, which suggested that Joey was structuring his argument based on his understanding of the overall experiment.

In the development of his arguments both in the introduction and discussion section, Joey describes using the literature. While Joey used the university library search engine to find sources, he discussed the difficulty he had in understanding primary literature and talked about his preference for using secondary sources, which are much more accessible to him conceptually.

> Through the library website, is where I find my sources. We have some primary articles that are like included in this; I find when writing an introduction, secondary research articles I feel like are easier [Joey's Stimulated Recall Interview July 2017].

He continues to say:

> When primary articles are more specific towards a specific topic like very specific where if we more or less if it's not on the same thing you are doing there is going to be a little bit off from like the information where like I cite secondary articles more in the introduction because it more or less gives you a specific topic like nutrient deficiency and just talks about that in general compared to a scientific article, or it can be nutrient deficiency of phosphorous or something like that [Joey's Stimulated Recall Interview July 2017].

Joey preferred to use more general information via secondary sources, as opposed to the narrow scope of primary literature. This suggested that Joey was more comfortable with a more general level of information, which he saw as more applicable. Furthermore, this suggested that Joey was able to enter into the literature when he processed the necessary discourse to interact with it.

When Joey was asked how he determined credibility, Joey relied on a recognizable scientific article structure to determine if a primary research article was credible or not. Furthermore, he suggested that if an author was affiliated with a university, then that article was more likely than not to be credible.

> I feel like just um hints throughout the paper it just I do not know like usually around pages it has or comes from like a university, universities are more or less credible. And uh, like a primary source will more or less maybe starts with an abstract and goes to an introduction methods, results, and discussion and um usually after like sources they have the main thing is you want to have their citations so you can if you need more

> addition info you could go to those if need be [Joey's Stimulated Recall Interview July 2017].

Here, Joey relied on criteria that he was familiar with, like the basic format of a scientific paper, a convention that was explicitly taught in the laboratory. Joey also relied on professional rank in order to determine article credibility, such as a university professor or researcher, as opposed to gauging credibility on the merit of the experimental design, findings, and conclusions.

While Joey relied on structural criteria to gauge credibility, Joey did demonstrate that he knew how to effectively source information from and incorporate sources into his scientific writing. When asked how he sourced information from the primary literature, Joey discussed starting with the abstract and the introduction and trying to use the results to compare and contrast his research to other research.

> I want to look at the abstract introduction, and I will probably say results. You do not want to get too in detail with someone else's discussion when you are just comparing. I feel like when you are comparing something you want to look through for their results and see what they came up with — more or less introduction of just methods they used and all that. I do not look at their method or what they do [Joey's Stimulated Recall Interview July 2017].

Joey explicitly described not using the methods section to source information from for comparison to his experiment. While the methods section may not be directly cited from for comparisons, they could be used to help explain results; therefore, the conclusion that the researchers make could be directly related to their methods, and therefore he should look and understand what methods they are using. This could also be used during the comparison if the researcher is using different methods with similar hypotheses and results. This speaks to Joey's limited discourse and experience reading and interacting with primary research articles.

There were instances where Joey attempted to use the literature to compare and contrast his findings but did so in a limited capacity. For example, during the think aloud protocol intervier, Joey was asked if he compared all of his results or just one of his results, stomatal density, to the literature.

> R: Did you compare other results to the literature or just your stomatal density?
>
> Joey: I think I compared my photosynthetic pigments as well. I also talked about plant height from its roots, so I compared it to four things based on what they saw. I could not find anything about the number of leaves; I feel like that is an odd experiment to say someone that would have a high level of doing these experiments would count the number of leaves [Joey's Think-Aloud Interview July 2017].

Also during the think-aloud protocol interview, Joey's peer-review partner, David, noticed that Joey's discussion section would have been stronger if he included more comparison of Joey's experimental results with existing experimental results in the literature.

> David: …I would talk about a little bit more about um how do your results compare to the data from the literature…[Joey's Think-Aloud protocol Interview July 2017].

Here David offered Joey advice on how to strengthen his discussion section by incorporating more primary literature to make a stronger comparison. In his final draft, Joey did attempt to include a comparison of experimental results using published data.

> While some hypotheses were not supported, differences were showing between 0% phosphorus deficiency and 100% phosphorus deficiency. Comparing the experimental

results with an experiment by Oxford University shows many of the similar trends (Jensen et al. 2002). Their findings showed hinder growth in plants in different tests. Stomata density was increased in plants containing no phosphorus. This is showing that more CO_2 is in the plant compared to when phosphorus is included in plants. Plant height, from the roots to the stems of the plants were also hindered when phosphorus was not included. These findings show there are effects on phosphorus deficiency, but with the numbers that were not significantly different for photosynthetic pigments and stomatal density, the hypothesis cannot be supported [Joey's Final Manuscript Draft July 2017].

While Joey did attempt to include more comparison, his comparison suggested differences between experimental groups, but Joey did not include specific comparisons to his data to support his conclusion and therefore support the claims he was making in his argument with experimental evidence.

7.3.2 Science as Process:

Across all of Joey's interview data and written artifacts, all four themes associated with the *Science as Process* domain (Table 4.1) emerged. Joey explicitly discussed convention in scientific manuscript-style writing; however, he often geared his writing to the manuscript-style writing assignment rubric. Joey did rely on his prior knowledge of science disciplinary practices, but still had difficulty understanding how to interpret statistical analysis, specifically when the findings were not statistically significantly different.

Throughout the entire study, Joey demonstrated a strong understanding of the conventions of scientific writing. He was able only to meet conventions in his writing, but he was also able to help address conventions that were missing from David's paper.

> Joey: Is there; I do not know. I feel like it would be a better flow of the paper if you just took out all of the um subsections. I have never seen subsections in intros before [Joey's Think-Aloud Protocol Interview July 2017].

David's argument in his introduction was organized in subsections based on the rubric while reading through his rough draft; Joey suggested that the organization of his introduction disrupted the flow of the introduction and often left him confused about what the argument that David was developing was saying. Likewise, Joey relied on his knowledge of the conventions in scientific writing to guide his feedback. Furthermore, he was able to help David write in a more academic voice. While Joey was able to help David write in an academic voice, Joey struggled himself when he had to write about his methodology, particularly in the experimental design and replicates of the experiment.

> R: I have a question for you. Was the experiment replicated six times or were there different measurements or treatments?
>
> Joey: What I talked about first was the basic layer of setting it up. Six quads were made, one for each group and then I said these steps were completed six times for a total of six quads. I put comma replicating the experiment six times as it is, but it was before I said before I put the differences [Joey's Think-Aloud Protocol Interview July 2017].

Joey was not grasping the idea of one experiment with different methods, treatments, and replicates. For example, in his final paper, Joey did not address the three levels of treatment in his plant set up, thus, leaving out a description of critical method, his independent variable. While Joey did demonstrate a strong understanding of scientific conventions, he also demonstrated a difficulty translating his knowledge of scientific writing conventions into his actual written artifact.

Joey later went on to include his treatment levels in his final draft but still did not include how the nutrient being manipulated was applied. Furthermore, there were different replicates completed for the different methods. For example, stomata had four replicates per treatment, whereas plant height had more than four replicates per treatment. This suggested that there was some disconnect that Joey experienced between the experimental protocol and the overall experimental design.

Even though there may be some disconnect between the experimental design and the number of replicates, Joey did demonstrate an understanding that he was testing his hypothesis multiple methods.

> I think we can just because there are different things we can measure to support my hypothesis. I wrote that there were multiple parts. I said that we could compare zero percent deficiency towards 100% deficiency by comparing multiple variables like height number of leaves, stomatal density, and chlorophyll and photosynthetic pigments, so I had multiple back-ups, I want to say backup plans where maybe if one was not significantly different. I feel like just more experiments of even different things or keep repeating them could help strengthen the methods [Joey's Stimulated Recall Interview July 2017].

Joey recognized that different variables could influence the hypothesis. Joey did not talk about the third treatment group that he used in the experiment (50%). While Joey was missing some of the reasoning behind the experimental design, he did imply some level of optimization of methods, which was a more advanced skill.

During David's review of Joey paper, he also noticed that Joey was missing a critical method, the analysis. Joey was unable to articulate how to add this section to his written manuscript-style writing assignment because he did not complete the analysis of his experiment. His results were analyzed for him, and he was only required to report the results and create graphs and tables appropriate for the data.

> What should we include in that because basically we just put them in an excel sheet and she did everything for us so? Just add a paragraph on the data analysis of the means and like to put that in the introduction too for the photosynthetic pigments and plant height number of leaves and all of that [Joey’s Stimulated Recall Interview July 2017].

David suggested that he should also include his statistical testing; however, Joey never incorporated this method into his final draft of his plant nutrition paper. The lack of incorporating this section suggested that Joey was at a disadvantage when writing and interpreting the results of the experiment since he had limited knowledge of how the data was analyzed. This is corroborated with the way that Joey discusses the results of his manuscript.

> Results are just graphs and tables for me when I write. Along with figures and tables, I include a written section giving the exact numbers so if people reading the experiment need the exact, they can refer to the written section, or if they need a round-about answer, they can refer the graphs [Joey’s Stimulated Recall Interview July 2017].

The figures and tables presented in the final manuscript were neatly constructed and contained all the appropriate components including axes labels and figure captions. For the written portion of the analysis, there were no trends included; rather, Joey reported his statistics and conflated them with trends. For example:

> The average plant height for 0% phosphorus deficiency, 50% phosphorus deficiency, and 100% phosphorus deficiency was 19.40 cm, 19.90 cm, and 16.68 cm respectively. Standard deviations were found to be 3.26, 4.46, and 6.10 respectively. Standard errors for 0% phosphorus deficiency, 50% phosphorus deficiency, and 100% phosphorus deficiency were 0.58, 0.79, and 1.08 respectively. The p-value for 0% deficiency and 50% deficiency was 0.65, which is not significantly different. The p-value for 50% deficiency and 100% deficiency was 0.024, which is significantly different. The p-value for 0% deficiency and 100% deficiency was 0.033 which is significantly different [Joey's Final Manuscript Draft July 2017].

There were significant results in this section, which he correctly identified. Even though he correctly interpreted his statistical results, in terms of p-values and alpha levels, Joey went on to describe his data as not being significant (above 0.05) and that his hypothesis could not be supported due to a lack of significant data.

> Showing these trends helped show that my data showed similar trends, but because of the p-values being above 0.05, I could not support the hypothesis [Joey's Stimulated Recall Interview July 2017].

Joey demonstrated some difficulty interpreting his statistical tests. In his written manuscript-style writing assignment some p-values were presented that were significant suggesting that while Joey can report the results of his statistical analysis in his writing, he misinterpreted the outcome of his statistical test as he had multiple significant test results. Furthermore, Joey only focused on two of his treatments as opposed to all of his treatments.

> Just on the fact that I saw a lot that the 0 percent deficiency and the 50% deficiency of phosphorous it sometimes really didn't see a big change, so I focused my while we did 0%, 50%, and 100% I mainly focused on 0% and 100% deficiency because 50% deficiency in like say 0% deficiency really didn't have significant results compared to 0% and 100% [Joey's Final Manuscript Draft July 2017].

Joey was reporting that he included the data that seemed to have differences and left out one of the treatment groups. Here, he violated a convention where all results should be presented, regardless of the outcome of the statistical test out; even if it is to say that there was no difference.

> For example, when I compared the stomatal density in my discussion and the cited literature paper, it showed there was a difference when it was at 0% deficiency and 100% deficiency, which in my results showed, but I could not support it because the p-value was not significant [Joey's Stimulated Recall Interview July 2017].

Here, Joey demonstrated difficulty negotiating non-significant results and relating them to the overall data trends. Joey suggested that his data supported a trend between 0% deficiency and 100% deficiency; however, his data was non-significant and it did not statistically trend. This suggested that Joey recognized that there was no difference between statistically significant groups. Joey was also unable to interpret why he might see insignificant results.

7.3.3 Science as Sociopolitical Factor:

Across all of Joey's interview data and written artifacts, the one theme associated with Science as a Sociopolitical Factor domain (Table 4.1) emerged. Joey was only able to discuss a sociopolitical topic upon prompting in his stimulated recall interview. The emergence of this theme was further supported by Joey's lack of including a sociopolitical topic in his manuscript-style writing assignment.

When Joey did discuss how his experiment was directly related to a larger societal issue, he discussed how his research could contribute to basic knowledge of nutrient deficiencies and how that might apply across different climates. However, he was unable to connect how larger sociopolitical issues might impact his science experiment directly.

> Well, more or less this whole project was about plants which plants are important for everyday life so basically finding uh nutrient deficiency helps in the society of knowing what kind of nutrients are in plants compared like for example this one is just nutrient deficiency but like we could make this into a more bigger picture of nutrient deficiency in different parts of the world like some are in the tropical region or the tundra region or something like that where these nutrients deficiencies will help us to determine the best like conditions for a certain kind of plant to um survive and basically give us oxygen [Joey's Stimulated Recall Interview July 2017].

While Joey could see that there might have been some level of connection of his experiment to the society, he was unable to tie one specific sociopolitical factor to the experiment directly.

7.4 Interesting Trends:

Throughout the think-aloud peer-review, Joey often relied on personal experiences that he had in order to provide feedback to his partner, David. Both he and his peer-review partner had different TA's. When Joey offered advice, the majority of the time, his advice was guided based on his TA's feedback from other drafts that he submitted for additional feedback. For example, Joey offered David feedback on how he should incorporate his figure legends.

> Joey: All like figures are supposed to be single spaced because our TA told us because it looks like it is a part of the paragraph [Joey's Think-Aloud Protocol Interview July 2017].

While Joey drew on his experiences with scientific writing and feedback from the instructor, it almost always was related to a formatting issue and not specific scientific content. For example, Joey helped David in his methods to be able to talk about the experiment using a more academic voice.

> Joey: Because I have the same when I because I wrote the intro and methods because our TA said if you wrote it three weeks ago she would actually look over it like the intro and methods and I asked her this question, do we write the lab group or do we ask each this group did this, or the group did that or did I just write it as I am doing by myself so and then she said I wouldn't mention lab groups like you want to base it on that, but I don't know if your TA said anything else.
>
> David: Ok. Yeah, she did not say anything about that, but I agree. I do not know how to make it sound without lab group you know because there are six stations.
>
> R: Talk it out.
>
> Joey: You just, well what I did for mine was I just did I talked about making one box so then I said there are six replicates.
>
> David: Ok. Let me write that down to fix that [Joey's Think-Aloud Protocol Interview July 2017].

While writing in an academic voice was a convention of authentic scientific writing, Joey focused on more technical language based on what his TA's feedback was even though there were more significant issues with the methods section that needed to be addressed. Joey's feedback suggested that Joey was relying on his past feedback to help provide constructive feedback for his peer review; but also that his past feedback experience was limited to grammatical feedback versus specific scientific content knowledge and argument construction feedback.

7.5 Case 7 Summary:

Joey's ability to discuss the development of his argument was the most complex out of any participant. His description of his description of how he constructed an argument was a reliable indicator of the *Science as Access* domain. He used his methods as a model to shape his process for writing his introduction, guided results, and also helped him develop his argument in the discussion section. While he clearly articulated his process for writing an argument, Joey had difficulty finding and incorporating primary literature, often relying on secondary sources, which he found much more accessible. Joey's use of the secondary literature limited his support of his argument to supporting basic facts versus experimental findings.

In terms of *Science as Process*, Joey had a strong working knowledge of the conventions of science writing and how to apply them, although he was not always successful. Joey had the most difficulty understanding his analysis of his data; this most likely attributed to his lack of completing the analysis.

Joey was unable to address any topic that related to *Science as a Sociopolitical Factor*. When he spoke about the broader impacts of his experiment, he often talked about it in a knowledge-driven way. For example, he would describe building the public's knowledge of plant nutrients as opposed to how his science could be either directly or indirectly influenced by social, cultural, or political impacts.

Finally, in Figure 4.8 below, I offer a representation of Joey's science literacy as it was demonstrated in her data aligned in the conceptual framework of this dissertation study. Within the three domains, I included the themes that were evident across all sources of her data and supported by the excerpts in this case description.

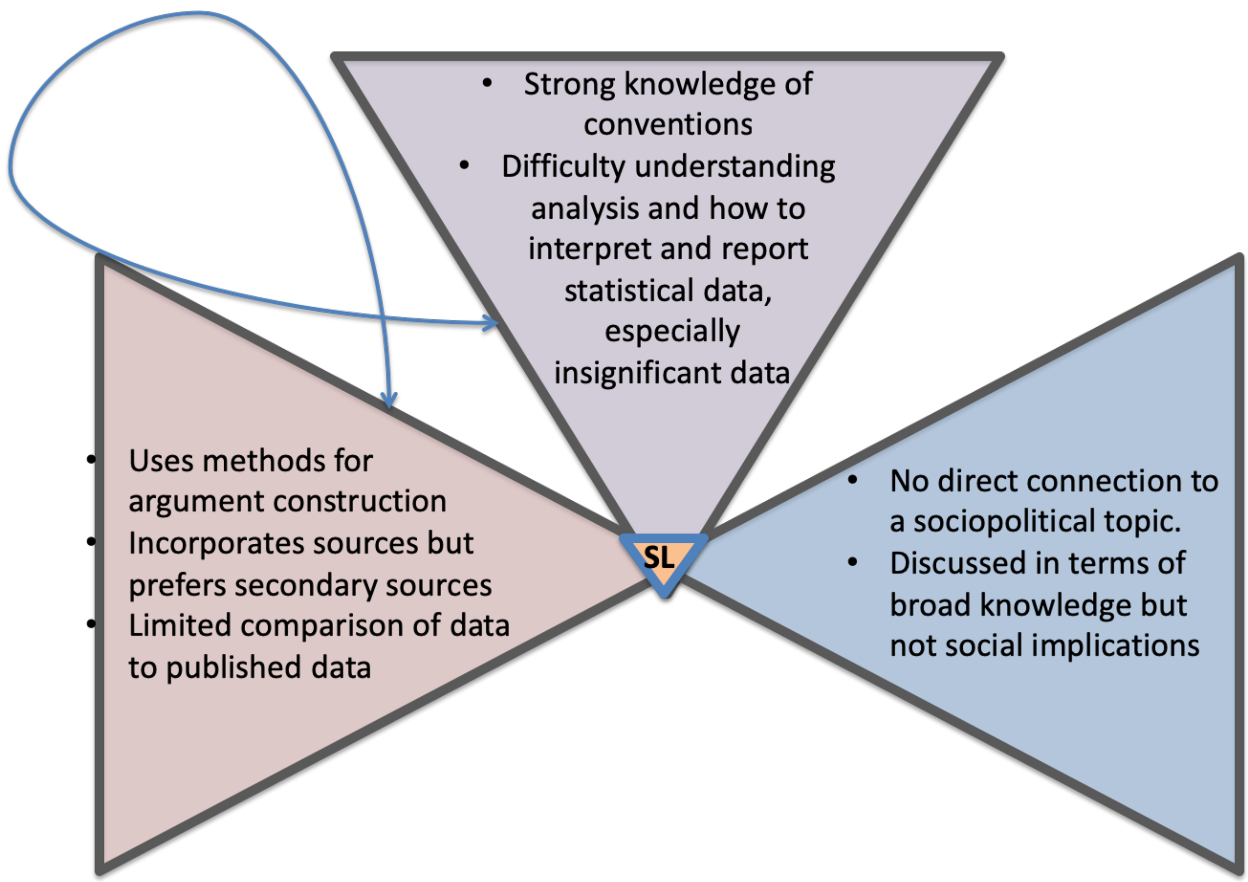

Figure 4.8: Joey's Science Literacy: Summary of Joey's science literacy mapped onto the conceptual framework. Joey developed his argument and results around his experimental design. Thus, he demonstrated a connection between *Science as Access* and *Science as a Process*.

Case # 8: David

8.1 Background

David was an undergraduate Psychology and Chemistry, double major and completed BIOL 115 with the grade of a C+. David described his background in science as good in chemistry and physics, but overall lacking in the biological sciences. Although David had not completed ENGL 101 yet, he described his ability to write in science as having a high ability. David attributed his interest in science, and the most influential person in learning science, to his chemistry professor. David also described his professor as both motivating and as a person who gave him opportunities to be successful; which David found particularly motivating. Lastly, David described his research experiences that had previous instruction in scientific writing, comprehension, and experimentation as out of school opportunities that have best shaped how he learns in the sciences.

8.2 David's definition and conceptualization of science literacy:

Danny was presented the conceptual framework and asked to describe what he thought the image meant. He described it as:

> Three different combinations of science literacy. Between Science as access, so accessing Science, getting information. Science as a process, actually doing the Science, doing the process, and Science as a sociopolitical factor, so um Science influences different aspects of life. Also, these lines around it show how they are all pretty related, but they are all come down back to science literacy [David's Pre-Interview July 2017].

Danny's description of the conceptual framework was similar to the way that the conceptual framework domains are designed. He continued to correlate the conceptual framework with the work in the classroom:

> Through school and then you learn how to do it, accessing Science is like getting that information and Science as a process is learning how it operates and then in my life, I guess sociopolitical factors are learning about outside the classroom things about how what you learn comes back and is influencing the world [David's Pre-Interview July 2017].

This description suggested that Danny was not only pulling from his experiences in the classroom, but also reflected on how his life experiences outside of the classroom helped him understand *Science as a Sociopolitical Factor*. When asked to define science literacy, Danny defined it as:

> To interpret things in a scientific respective and the whole process of research. I think it understands each section like the introduction, the methods, the literature review, the results the discussion so being able to interpret that data and like read it and understand it [David's Stimulated Recall Interview July 2017].

He further mapped his understanding of science literacy onto his writing assignment:

> I think it is um it starts with all of the background information we did on the topic and then it goes into each of the individual sections, like introduction, methods, the results and figures, and everything and to be able to write about that and know what is going on throughout the entire process. Science literacy, I think that it is asking the scientific question about societal implications, something that you are interested in, something

with background information done. A new research question is asked and doing your best to do the methods do the experiment, understand the results and discuss it and relating that back to your original question and understand and ask what can be done about it at the end [David's Stimulated Recall Interview July 2017].

Danny clearly articulated an understanding of science literacy and the integral components demonstrated through his manuscript writing assignment.

8.3 Emergent aspects of David's science literacy aligned with the three domains of my conceptual framework

8.3.1 Science as Access:

Across all of David's interview data and his written artifacts all three themes associated with the *Science as Access* domain (Table 4.1) emerged. David was able to draw on his prior knowledge and experiential learning to engage in scientific discourse; however, he had difficulty entering into the primary literature, which limited his ability to develop a strongly supported argument using the primary literature.

David's argument in his introduction was organized in subsections based on the rubric while reading through his rough draft. Joey suggested in the think-aloud protocol that the organization of his introduction disrupted the flow of the introduction and often left him confused about the argument that David was developing. Likewise, Joey relied on his knowledge of conventions in scientific writing to guide his feedback. I further probed into how David might incorporate Joey's feedback to develop his argument further.

R: What is a way that you could bridge those ideas if you are going to take out the subheadings?

David: That when you miss a nutrient that is a deficiency.

R: Right, I am talking about your subheadings so if you want to bring them all together into one cohesive section, how would you do that?

David: I think maybe transition statements yeah. Like saying like missing a nutrient that is a deficiency. Yeah, so having transition statements there would be good and have a better flow. I will write that down [David's Think-Aloud Protocol Interview July 2017]..

David recognized that he could replace his subheadings in the introduction with transition statements to bridge the ideas he was developing for his argument in his introduction.

Joey: Yeah, it was a good introduction. It hit a majority of the points but just some nitpicking here or there, for the first point I would probably [get more specific]. You start with the organisms, and I would probably more specifically talk about plants.

David: Ok [David's Think-Aloud Protocol Interview July 2017].

Here Joey suggested to David that he started off his argument too broad for the scope of the experiment and suggested that David focused his introduction more, perhaps starting with plants. While David agreed with the suggestion from Joey and even discussed how he could incorporate the changes, David ultimately chose to keep the existing structure of his introduction for his final manuscript.

I used the rubric as a good guideline for that but um definitely wanted to get the right background information into the um report so really focusing in on magnesium deficiencies [David's Stimulated Recall Interview July 2017].

Danny described that he had difficulty developing the argument in the introduction due to having difficulty finding relevant primary sources and thus he had difficulty developing his hypothesis.

> The literature review was a little bit difficult just because there was not a ton of information or studies available about magnesium deficiencies. The hypothesis was also hard to construct because I was confused about the relationship between chlorosis, pigmentation, and stomata [David's Stimulated Recall Interview July 2017].

Even though he had difficulty finding literature to support his argument, David was still able to develop one by using the rubric to help construct his argument.

As opposed to using the rubric as a skeletal outline, David used the bullet points within the rubric to create subheadings in the introduction as opposed to developing a cohesive argument guided by the scaffolding of the rubric. For example, for model species information:

> Model Species Information
>
> Brassica rapa is an extremely fast-growing plant. It is a great model for an experiment because of the fast and consistent growth. When fully grown, B. rapa has many green leaves and may even have yellow flowers [David's Final Manuscript Draft July 2017].

However, because of this structure and reliance on the rubric, David's use of subheadings created a disjointed introduction. While the flow of his introduction was disjointed, David was able to demonstrate the logic necessary to develop his argument when he wrote about the methods that he selected to test his hypothesis.

> For example, with the stomatal density, we hypothesized the fewer stomata, the less healthy the plant would be and then with the stomatal density it measures the number

> of stomata, so it gives like quantification of what we hypothesized in the introduction [David's Stimulated Recall Interview July 2017].

This pattern of reliance on the rubric to help create arguments was also seen in the discussion when trying to make meaning of the result of the experiment.

> We start with the introduction with plant deficiencies and then also the hypothesis and the objective for the data, my project, for example, was not significant, so one of the things we had to look at was the methods. Were the methods done correctly? What experimental error could there have been? I looked to incorporate the methods that way. Was this the right way to measure magnesium deficiency? To look at all of those things, then for the results we looked at how could these results be better in the future what could we do to make this, why did we get these, like why what went wrong or what went correctly in the data that um gave us these results? [David's Stimulated Recall Interview July 2017].

David's description of the argument created for the discussion section was similarly formatted to the rubric. David attributed his struggles creating his arguments based on the limited availability of primary resources applicable to the study. When asked how he searched for primary literature, Danny reported using Google Scholar.

> I used Google Scholar, and then I typed in some keywords and then approached it like a literature review. I looked at like the first article that came up but also did a little more digging on the sites too to make sure I can get the best sources [David's Stimulated Recall Interview July 2017].

While David's literature search was not very focused and generally broad in scope, he was able to discuss how he would select sources and how he assessed them for credibility.

> I looked a lot about how many times they were cited. I thought that was important that and also the year that it was a more recent study done. I mean not too recent because plant deficiency is you know a new thing, but I wanted to make sure that something that is pretty you know not too old, not very current research done [David's Stimulated Recall Interview July 2017].

David was using a more sophisticated way of gauging credibility than his peers by looking at how many times an article has been cited. This suggested that David was not only looking for credible research but also seminal research that has been cited multiple times.

Not only did David use a more sophisticated method of gauging credibility of the primary research, David also discussed sourcing information from primary literature from the results and discussion section; a correct scientific conventions related to authentic science manuscript-style writing assignment and proper use of the primary literature.

> I start with the um abstract because that shows this study even worthwhile to the research that I am conducting so I start with that, and I go, and I download it, I look mainly into like the results and discussion [David's Stimulated Recall Interview July 2017].

Most advanced readers skim the abstract to see if it is worth reading. David also reported sourcing his information from the results and discussion section, which is the correct way to source information. While David discussed how to properly source information, when specifically asked how he would include literature into his paper, he discussed using the same sources in the introduction and the discussion.

> I cited one source that I used in the introduction too. I used the same because I went back to it talking about the magnesium deficiencies and then I also found a new article that talked about the relationship between magnesium deficiencies with other deficiencies and that's maybe why we did not find anything is because magnesium deficiency might spike when other nutrients are not available too [David's Stimulated Recall Interview July 2017].

Furthermore, David had difficulty finding literature reviews that pertained to magnesium so that he could use that to compare it to his results.

> The resources there were not any literature reviews that were just magnesium that looked solely on that in a controlled environment like this study that I could find. However, other studies showed that magnesium deficiency should be significant, so that was competing, but that is what we expected. However, none showed that magnesium, which I could find at least, magnesium deficiency would be insignificant on the plants [David's Stimulated Recall Interview July 2017].

David was able to identify that he was finding competing literature and discussed how he addressed the competing results in his discussion section. While David did address the discrepancy in results, he did not present the results of the study; therefore, this demonstrated that David had difficulty incorporating the literature correctly.

8.3.2 Science as Process:

Across all of David's interview data and written artifacts, all four themes associated with *Science as Process* domain emerged from the data. David demonstrated a reliance on his prior knowledge and was easily able to discuss scientific conventions clearly and correctly. During his think-aloud protocol interview David demonstrated that his revisions of Joey's paper, David drew on his prior feedback provided from his TA and used that information to guide his ability to give feedback. Furthermore, David had difficulty interpreting his statistical results. Lastly, David often conformed his writing to meet the expectation of the manuscript-style writing assignment rubric.

Danny discussed the conventions that are involved in scientific writing; however, he was not always able to incorporate those into his writing assignment. For example, during the think-aloud protocol, Joey discussed with David that he was not meeting the convention for using scientific names.

> Joey: And I do not know if I noticed this other, but the B.rapa after you do the abbreviation all of those are italicized.
>
> David: They are? [David's Stimulated Recall Interview July 2017].

Here, David was unaware of some of the conventions of scientific writing related to incorporating scientific names of species, even though he was familiar with others. This suggested that while David was confident in his abilities to discuss scientific writing conventions, suggesting that David had room for improvement within the *Science as Process* domain. Moving through the peer review seemed to be especially beneficial for David editing his paper.

> David: Yeah. (reading paper) I am changing lower pigment measures from measures to lower concentrations.
>
> R: Why are you making that change?
>
> David: Um, because I thought measures were a little vague and it is concentrations [David's Think-Aloud Protocol Interview July 2017].

It appeared that David could make edits suggested by Joey during the think-aloud peer-review; however he chose not to incorporate them into his final manuscript draft; instead he relied on his TA feedback. The process of going through Joey's paper seemed to help David think not only about the experiment but also how he articulated his edits and effectively discussed the experiment. Furthermore, David mentioned that the ability to peer-review in real time was beneficial to him.

> It allowed a conversation about the paper and the possibility to work together to make sure each other's papers were the best they can be [David's 2nd Metacognitive Reflection July 2017].

Understanding what the expectations are from a peer and an instructor allowed David to gain a better understanding of the conventions of science writing. He was able to carry these conventions that he learned outside of the peer-review and into understanding how to edit his manuscript draft.

David described writing his results as quick and easy because he wrote them as he completed the experiment; however, David's methods followed the format of the lab manual and often contained more detail than necessary, a typical error seen amongst novice writers.

> Methods were quick to write because I wrote it in steps as we completed the methods in the lab… however, doing things ahead of time was a strength in this lab report for me [David's 1st Metacognitive Reflection July 2017].

David further described that he divided his methods into subsections for ease of reading. His TA suggested this approach.

> I divided it up into each method. So, we did like the first day we did the planting, then we did like the pigments, like what each step was. I did a little subheading, and then I used what we did and made sure that was not and then made sure that it was past tense and not as a list of instructions [David's Stimulated Recall Interview July 2017].

Here, David described the conventions for writing the methods section, which he displayed a clear understanding of the conventions of the methods. David continued to start to discuss the results section as one that he is confident about writing.

> I felt strong about my results section even though the graphs were extremely difficult to make. However, once I had the graphs, I knew how to describe them well with legends and trends [David's Stimulated Recall Interview July 2017].

While David reported the figures themselves were difficult to make, all of the figures included were completed correctly and included descriptive figure captions with trends in the data presented. There was a disconnect between his data and when David had to write his written results section. David did not include the trends discussed in the figures in his written manuscript-style writing assignment draft.

> I started with figures and made all the graphs of the data, and those showed, the trends they could also give us our p-values and stuff like that. We conducted the t-test. I

> started with that to get the numbers, found out that none of the data was significant so I decided to start writing it. Saying that it was not interesting but still talk, not interesting but significant, that is interesting though that it is not significant but can keep writing about some trends in the data and what could be incorporated next to make this experiment better [David's Stimulated Recall Interview July 2017].

Here, David discussed his process for writing the results section. In his original manuscript draft, David does not present any trends for any variable, for example:

> None of the p-values for the chlorosis part of this experiment were statistical. They were all greater than .05 (100% VS 75% p=.0943, 75% VS 50% p=.7658, 100% VS 50% p =.1285). The chlorosis data is not significant. However, the p-value comparing 100% and 75% deficiency is the closest to significant at .0943 [David's Final Manuscript Draft July 2017].

David was only presenting the results of the statistical analysis. Furthermore, David only included data from three methods, chlorosis, stomatal density, and photosynthetic pigments. When transitioning from the results to the methods, David described loosely following the rubric format.

> I wanted to start a big part of this research project with the hypothesis. So, I wanted to start with the hypothesis and the objective talking about was it met what was what went on with that; I wanted to really get to the main points there and then elaborate as it went on to go into some more details [David's Stimulated Recall Interview July 2017].

While David was able to follow the format of the rubric for the discussion, and he was able to reiterate the expected results of the experiment, he was unable to effectively interpret his results due to their lack of significance of his experimental results.

> We did see some interesting relationships and stuff, but that nothing was significant, we really cannot say that the objective was fully met to understand these relationships [David's Stimulated Recall Interview July 2017].

David was not comfortable talking about insignificant results or did not understand how to approach insignificant results. Furthermore, the insignificant data was difficult for David to decide as to whether his hypothesis was supported or not.

> The only reason I said that it was only partially supported because you cannot say that there are any relationships because they are not significantly significant but there are things that are interesting to look at, but with like future tests it might be good. That is what like I kind of mean but if it is confusing I could change it [David's Stimulated Recall Interview July 2017].

In his reflection, David also mentioned how the discussion was the most difficult to write based on the insignificant data.

> The discussion section was the hardest part for me. All of the p-values were insignificant, so I had difficulty discussing this experiment at all without just saying that it failed [David's 1st Metacognitive Reflection July 2017].

David was not alone in his difficulty interpreting insignificant data as this was a consistent issue suggested by all eight participants interview data and written artifact data.

8.3.3 Science as Sociopolitical Factor:

Across all of David’s interview data and written artifact data, the one theme associated with *Science as a Sociopolitical Topic* domain (Table 4.1) did not emerge from David’s data. David was able to discuss a sociopolitical topic in relation to his experiment in both his written artifact and was able to elaborate on this in his interview data when prompted. David was also able to support his sociopolitical link using the literature in his final written manuscript-style writing assignment draft.

In his final manuscript, David did mention a connection to a broader societal context.

> There are also many ecological implications to deficiencies when looking at the environment and external forces. For example, flooding and pesticide use can cause magnesium deficiency, sometimes killing the plant (Dordas, 2009) [David’s Rough and Final Manuscript Draft July 2017].

What was interesting was that David's group won the proposal for the lab. In that proposal, the group was instructed to include a broader significance for the work. In his interview, David was further articulated what his group talked about in their proposal concerning the societal implications of the experiment.

> Our group talked about a few of the societal things, so it's vast in flooding, in pesticide use and has actually been a problem in West Virginia, so that was like a big societal thing that I think is one of the reasons that our group got chosen is because magnesium deficiency is really applicable in our area [David’s Stimulated Recall Interview July 2017].

However, when David was asked how his results relate to a societal connection he responded:

> It was looking at magnesium deficiency and looking at that societal implications, but I guess because it was insignificant, it just shows that more research needs to be done in

> this to understand the role of magnesium deficiency in the society [David's Stimulated Recall Interview July 2017].

It is not clear that David grasped how these results might link back to the overarching societal issue that he discussed in the introduction section; which further suggested room for growth within the *Science as a Sociopolitical* Factor domain of science literacy.

He clearly understood that there was direct implications on magnesium in West Virginia agriculture and its ties to fertilization, but he was not able to connect the results of his experiment to that larger picture. Interestingly enough, he did mention that there was a limitation to the study in that magnesium is typically studied as a co-nutrient but not by itself in the more current literature.

8.4 Interesting Trends:

David demonstrated a clear understanding of the experiment and was easily able to discuss the experiment; however, he described difficulties in writing about the experiment. For example, David could address questions that his think-aloud peer-reviewer Joey asked. Furthermore, he could offer a more detailed answer that was not present in his writing. David's dissonance did not seem to be tied to a lack of understanding about the experiment itself; rather his dissonance seemed to be tied directly to David's scientific writing process.

David was able to address edits and suggestions made during the peer-review actively; however, no matter how critical the feedback Joey provided to David, David did incorporate any changes from his rough draft to his final draft of his manuscript-style writing assignment; thus, further supporting that David struggled with writing scientifically.

8.5 Case 8 Summary:

David could clearly articulate how to find literature, correctly source information from the proper section of the paper, and gauge it for credibility. While David could discuss this, he did not demonstrate it in his writing. For example, he demonstrated difficulty incorporating the literature effectively into his arguments both in the introduction and the discussion sections. Lastly, because of David's difficulty finding and incorporating literature into his argument, he often relied on the rubric to structure his arguments in the introduction and the discussion section, which led to disjointed and weakly supported arguments.

Like for *Science as Access*, David also could articulate the conventions of scientific writing through his interviews and think aloud peer review; however, he had difficulty demonstrating those conventions in his writing. Additionally, David had difficulty interpreting his insignificant data when he expected there to be actual differences in the treatment groups.

For *Science as a Sociopolitical Factor*, David continued to have the same pattern where he could clearly articulate how his research would be related to a sociopolitical factor, but he could not translate that understanding into his writing. David also had difficulty linking the results of his experiment to a sociopolitical topic even though he was easily able to discuss it in his interview for his introduction.

Finally, in Figure 4.9 below, I offer a representation of David's science literacy as it was demonstrated in her data aligned in the conceptual framework of this dissertation study. Within the three domains, I included the themes that were evident across all sources of her data and supported by the excerpts in this case description.

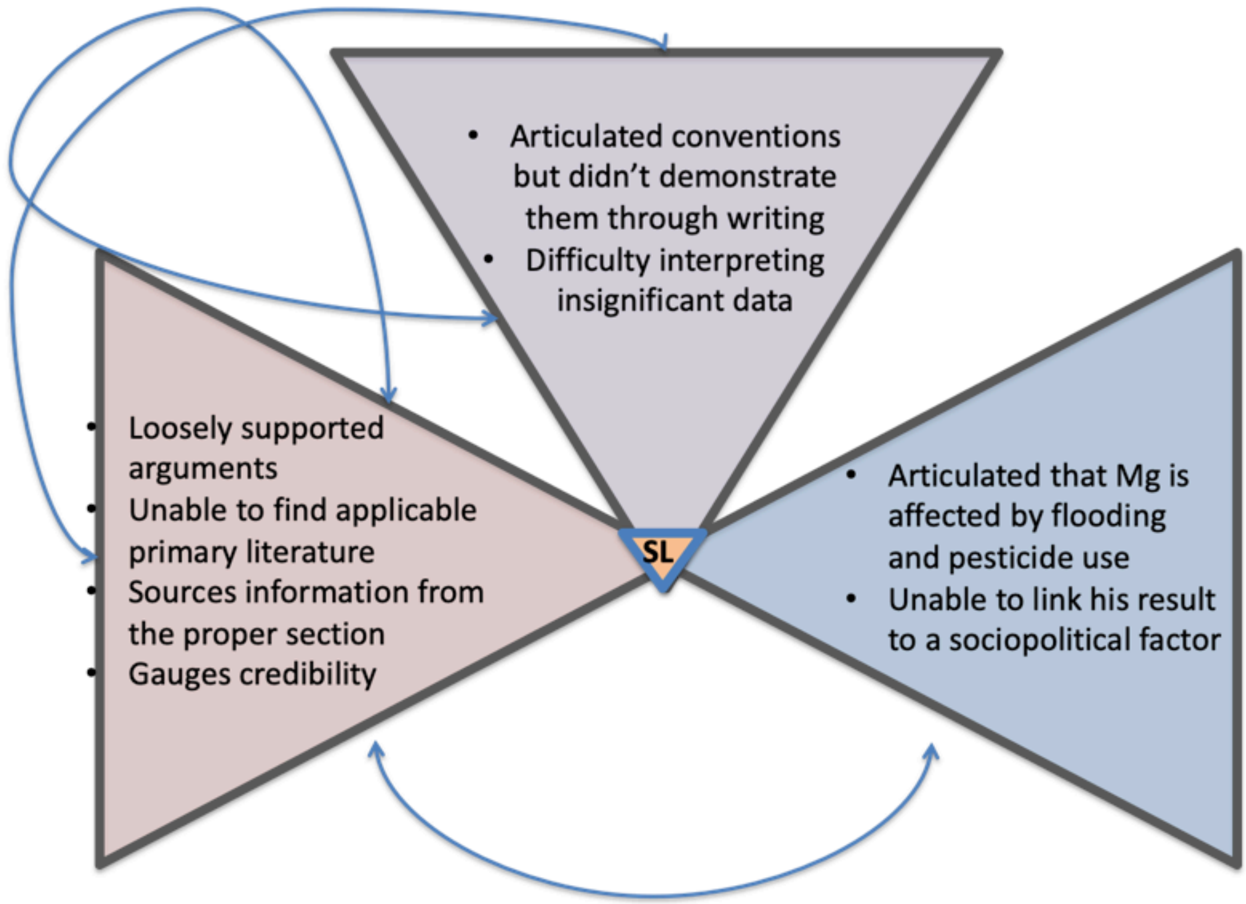

Figure 4.9: David's Science Literacy: Summary of David's science literacy mapped onto the conceptual framework. David used the literature to support basic facts about the methods that they used and developed a justification for using the method to study his deficiency. Furthermore, he used the literature to develop a sociopolitical factor. David also demonstrated using his results to compare and contrast experimental findings.

Rubric Analysis:

The assignment rubric was analyzed for aspects of science literacy using the codes derived from the conceptual framework. Six of the eight sections of the rubric were analyzed for scientific literacy, excluding the title section and the writing style portions of the rubric (See full rubric, Appendix G).

Introduction:

The majority of the components from the introduction aligned under the *Science as Access* domain of the conceptual framework. For example, the introduction focused on building an argument that was supplemented and supported by primary and secondary literature. The first bullet point focused mainly on the content that is necessary to build the argument. This section of the rubric was highly scaffolded and provided a skeletal outline for an argument (Figure 4.10). While the introduction focused mainly on skills that would align under *Science as Access*, there were also aspects of the *Science as Process* domain and the *Science as a Sociopolitical Factor* domain present in the introduction.

The hypothesis generation of at the end of the introduction was both a *Science as Access* skills because the argument and the literature used to support it should be used to develop a reasonable hypothesis, and *Science as Process* skill because generating hypotheses associated with experiments was a standard part of "doing" science. While *Science as a Sociopolitical Factor* domain was not explicitly described in the rubric, it was implicitly as part of the broader significance required of the introduction and as part of the argument that the student should have constructed based on scientific writing conventions.

Introduction	**_____/ 25 pts.**
_____/ 3 pts. _____/ 7 pts. _____/ 1 pts _____/ 2 pts.	☐ Introduction starts with accurate, relevant background information that helps the reader to build a picture of the topic to be discussed. Keep your audience in mind; write for your peers, a general audience of beginning college students. - *Plant nutrients:* What is an essential nutrient? What are micro-and macronutrients? Where do they come from? - *Deficiencies, general and your specific deficiency:* Why are they important? What happens if a plant lacks an essential nutrient? What functions could be affected or disrupted? What are typical characteristics of deficiencies? What causes deficiencies? How/why do you artificially create deficiencies in the lab? - *Model species information:* Why is *Brassica rapa* a good model? - *Techniques introduced:* Quantification of stomatal density. Photosynthetic pigment measurements using spectrophotometry. Growth measures. Other deficiency symptom measures.
_____/ 4 pts.	☐ Appropriate rationale is included; the reader will understand the scientific reasoning for doing the research and how it adds to the body of current research.
_____/ 5 pts.	☐ All information is derived from or supported by appropriate sources (primary literature, reliable secondary sources, NO websites). At least five sources are required for the full report. A minimum of three should be primary sources. - If any secondary sources are used, they are reliable (e.g. review articles, textbooks) - References indicate an extensive primary literature search was done. Helpful resources include Academic Search Complete or Ebscohost through WVU Libraries (www.libraries.wvu.edu) and Google Scholar.
_____/ 3 pts.	☐ Purpose or objective of research is clearly stated and is included at the end of the Introduction section. A properly written hypothesis is also acceptable.

Figure 4.10: Plant Nutrient Report Assignment Rubric-Introduction Section: This piece of the rubric highlights aspects of Science as Access, Science as Process, and Science as a Sociopolitical Factor domain.

Methods, Results, and Figures and Tables:

The next three sections of the rubric, Methods, Results, and Figures and Tables, all fell under the *Science as Process* domain. This domain included all aspects of doing Science, including completing experimental methods, analyzing, and reporting data. Following the specific conventions within scientific writing and the scientific process were also incorporated into this domain as demonstrated by narrative style and tense preference in the methods, and standards of graphical representation in scientific writing in the figures and table section (Figure 4.11). Like the introduction section, the methods section was highly scaffolded, and it was intended to help students list out all of their methods included in a manuscript draft. The results section was less scaffolded than the other two sections. The lack of scaffolding here aligned with student difficulty writing this section as they were often relying on the rubric which led to them being unsure of how to write accurate descriptions of data analysis.

Methods	_____/ 18 pts.
_____/ 1 pts.	☐ Written in complete sentences, not a bulleted list. Subheadings are included within the section. (E.g. "Experimental setup," "Measurement of photosynthetic pigments," etc.)
_____/ 2 pts.	☐ Written in past tense.
_____/ 1 pts.	☐ Not a list of instructions; avoids "First…Second…," or "Next…and then…," etc.
	☐ Level of detail is appropriate; Includes relevant details, does not include unnecessary information.
_____/ 2 pts.	- Experimental setup: number of plants, treatments, preparation of solutions, watering regimes, etc.
_____/ 2 pts.	- Measurement of photosynthetic pigments
_____/ 2 pts.	- Stomatal density
_____/ 2 pts.	- Plant growth and biomass, any measurements repeated over time
_____/ 1 pt.	- Description of data analysis (means, standard error, t-tests, etc.)
_____/ 5 pts.	☐ Someone could reproduce the procedure after reading your methods section.
Results	_____/ 10 pts.
_____/ 2 pts.	☐ Section is written in complete sentences.
_____/ 6 pts.	☐ Descriptions of data/figures are relevant, accurate, and complete. All important data trends and findings are included.
_____/ 2 pts.	☐ Statistical p-values are reported. Significance/non-significance is indicated.

Figures & Tables	_____/ 15 pts.
	☐ Graphs of data are included
_____/ 2 pts.	- Graph types are appropriate (line graph for continuous data or bar graph non-continuous data)
_____/ 2 pts.	- Data points represent means
_____/ 2 pts.	- Standard error bars are correctly calculated and included on the figures
_____/ 2 pts.	- Axes have labels with units
_____/ 2 pts.	- Overall the graphs are neat and clear
_____/ 5 pts.	☐ All figures and tables have a description/legend and are placed above tables and below figures. The description/legend contains a title and brief description of what is shown.

Figure 4.11: Methods, Results, Figures and Tables Rubric: This piece of the rubric highlights many aspects of the Science as Process domain, containing all process skills about doing Science, analyzing Science, and presenting results of experiments.

Discussion Section:

The discussion section contained aspects of all three domains of science literacy. The discussion section began with *Science as Process* domain skills. Students had to interpret their experimental findings, again a critical component of the scientific method. Students were expected to compare and contrast their results with other primary research findings, a *Science as Access* domain skill. Future directions included both *Science as Process* domain skills and *Science as Sociopolitical Factor* domain skills (Figure 4.12). For example, articulating limitations and possible error requires an understanding of the experimental approach. Like the introduction, *Science as a Sociopolitical Factor* was implied in the rubric per scientific conventions. For example, a writer would discuss the broader implications of their findings in the discussion, often linking it to the broader significance introduced in the introduction section. While there was some scaffolding in this section of the rubric, it was limited.

Discussion	**_____/ 30 pts.**
_____/ 3 pts.	☐ The author indicates whether or not the objectives of the experiment were met and/or whether or not hypotheses were supported.
 _____/ 4 pts. _____/ 4 pts. _____/ 4 pts.	☐ The class data is interpreted and discussed including: - Explain how your actual results compare with what was expected. - How do your results compare with data from the literature? Use existing information to put your results in context. - How can you explain any unexpected results? How might you test those possible explanations?
_____/ 8 pts.	☐ Future directions are discussed. Based on your results, what are the next questions you would logically want to ask next? You may include any limitations of the experiment and suggest how they might be avoided in future experiments.
_____/ 7 pts.	☐ All information is derived from or supported by appropriate sources (primary literature, reliable secondary sources, NO websites). At least five sources are required for the full report. A minimum of three should be primary sources. - If any secondary sources are used, they are reliable (e.g. review articles, textbooks) - References indicate an extensive primary literature search was done. Helpful resources include Academic Search Complete or Ebscohost through WVU Libraries (www.libraries.wvu.edu) and Google Scholar.

Figure 4.12: Discussion Section Rubric: This piece of the rubric highlights many aspects of the Science as Process domain, containing all process skills about doing Science, analyzing Science, and presenting results of experiments.

References:

The reference section was a part of the *Science as Access* domain as it reflected a student's ability to locate and adequately represent primary and secondary literature.

References	_____/ 10 pts.
_____/ 10 pts.	☐ Proper format is used to reference both in-text citations and in Literature Cited Section at the end of report. (See Chapter 5 in *A Short Guide to Writing About Biology* by Jan A. Pechenik for formats.)

Figure 4.13: References Section Rubric: This piece of the rubric highlights the critical aspect of the Science as Access domain, focusing on properly citing and including primary literature.

Rubric Summary:

The Plant Nutrient Report Rubric was provided to students as a means of assessment contained aspects of all three domains that encapsulated the conceptual framework of science literacy in this dissertation study. Two domains, *Science as Access* and *Science as Process* were explicitly described in the rubric; whereas, *Science as a Sociopolitical Factor* was implicitly incorporated into the rubric based upon scientific writing conventions. There was significant scaffolding for the introduction, methods, and figure and tables sections of the rubric, sections that students often associated with a feeling of confidence in their writing. In the results and discussion section, there was some scaffolding, but the scaffolding was limited. Students often reported that those two sections are the hardest to write when they were drafting their manuscripts. This suggested that the rubric not only provided a model for students to following, but also that they relied on the rubric when they had limited discouse about how to engage in disciplinary scientific writing practices for a particular section of their manuscript-style writing assignment.

Chapter Summary:

Chapter four presented the findings from eight pre-structured case studies exploring the authentic manuscript style writing process for introductory STEM students. The findings were presented in alignment with the conceptual framework as *Science as Access*, *Science as Process*, and *Science as a Sociopolitical Factor*. The rubric artifact associated with the manuscript writing assignment was also analyzed for emergent aspects of science literacy concerning the conceptual framework. Chapter 5 will present the analysis of the findings and how they can be applied to further understand the emergent aspects of science literacy in introductory undergraduate students' authentic writing in STEM.

Chapter 5: Discussion of Findings and Implications

The purpose of this dissertation study was to explore what aspects of science literacy emerged as students progressed through an authentic writing assignment. In an attempt to understand how introductory STEM students demonstrated different aspects of scientific literacy as defined by the conceptual framework, an exploratory study was conducted around an authentic writing assignment including drafts, metacognitive reflections, and peer review. My research was guided by the following three research questions:

1. How do students demonstrate science literacy at different points in the writing process as they work towards completing the manuscript style writing assignment?
2. How do course artifacts (manuscript drafts and the course rubric) related to this assignment demonstrate science literacy?
3. How do students talk about what it means to be scientifically literate?

In this chapter, I will interpret and situate these findings within the literature. The chapter is organized according to the themes that emerged and how they align with the conceptual framework (Figure 2.1). A more detailed description of each theme and associated codes are included, along with the domain that the theme is associated with (Figure 5.1). Embedded in the interpretation of the results, I will discuss the implications and suggest future directions for continuing on this research.

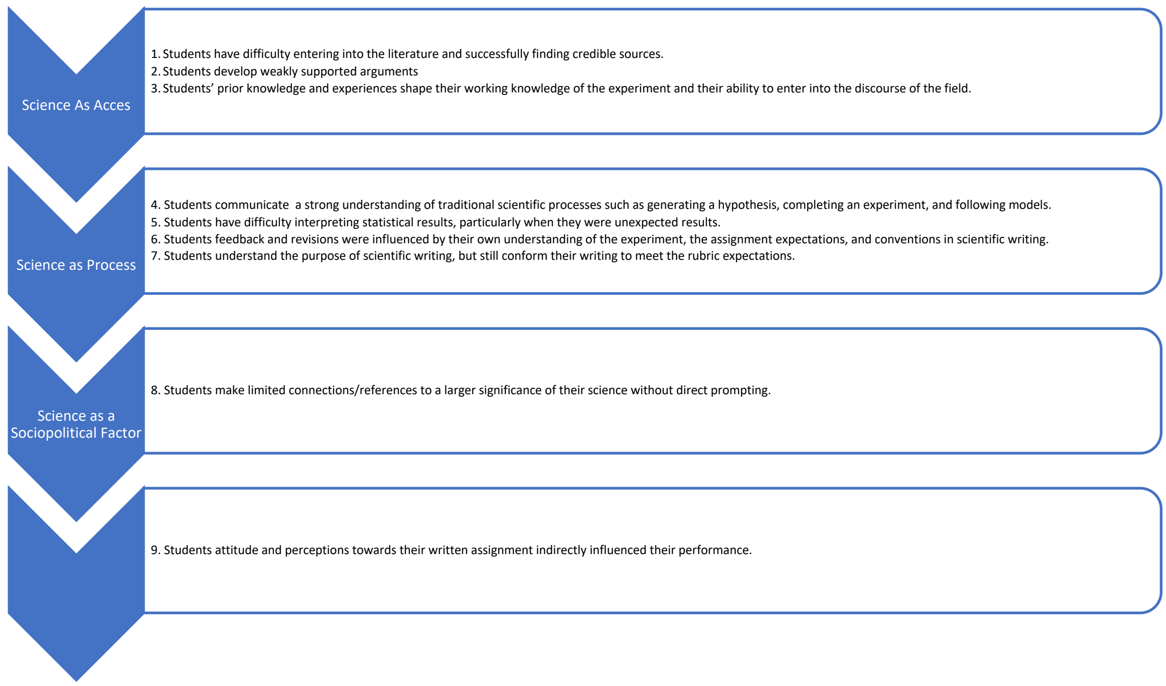

Figure 5.1: Emergent Themes Across All Eight Participants. 8 of the themes align with the conceptual framework whereas theme 9 is not directly tied to the conceptual framework but contributed significantly to the overall writing process.

Through the literature, I developed a conceptual framework in which I proposed a way to consider and define science literacy (Figure 2.1). In this conceptual framework, I proposed an equal contribution amongst all three domains, *Science as Access*, *Science as Process*, and *Science as a Sociopolitical Factor* in developing science literacy. Not only are the domains themselves integral components of science literacy, but also the interactions within and between the domains are critical in developing science literacy.

When exploring how introductory STEM students demonstrated aspects of science literacy through an authentic manuscript-style writing assignment in a laboratory course, I found that the domain distribution of the conceptual framework shifts. As opposed to showing an equal distribution across the three domains, introductory *STEM students showed an uneven distribution across the domains (Figure 5.2). Science as Process was the most prominent* *domain, followed by Science as Access, and lastly Science as a Sociopolitical Factor.* This uneven distribution of the domains was determined by the number of themes that emerged that were aligned with each of the domains.

It is not surprising that we see this uneven distribution across the three domains. Past research has focused on the individual components of each domain. For example, prior research has focused on how students find, read, and incorporate primary literature into their writing (Yarden, 2009; Sato, Kadandale, He, Murata, Latif, & Warschauer, 2014; Wenk & Tronsky, 2011; Van Lacum, Ossevoort, Buikema, & Goedhart, 2011; Hoskins, Lopatto, & Stevens, 2011). Across research similar trends are found that students have difficulty reading primary literature and incorporating it into their writing (Verkade & Lim, 2016). Other studies have found that undergraduate students benefit from scaffolded explicit instruction on how to read the primary literature (Janick-Buckner, 1997; Hoskins et. al., 2011). Furthermore, research has shown engaging students in authentic scientific processes increases students' interpretations of their results, their ability to generate new hypotheses, and design experiments (Roth & Roychoudhury, 1993). This research also demonstrated that students focused less on the right answer, thus becoming more adaptable thinkers that lead to the development of integrated process skills (Roth & Roychoudhury, 1993). We also know that when students engage in authentic science practices in which science is socially influenced helps students to for judgments, make life and social decisions, and use science to act (Grooms et al., 2014).

All of these studies focused on the individual domains and their components telling an isolated story. We know that studying the individual domains is not sufficient to develop science literacy as supported by a lack of science literacy across college graduates and the general public (Impey et.al, 2011; Roberts, 2012; Bensaude-Vincent, 2001; Peters, 2013). The main contribution of this work is showing that science literacy exists across these three domains and through their interactions. If we want students to develop science literacy, we need to address this uneven distribution across the domains and develop the interactions between each of the domains.

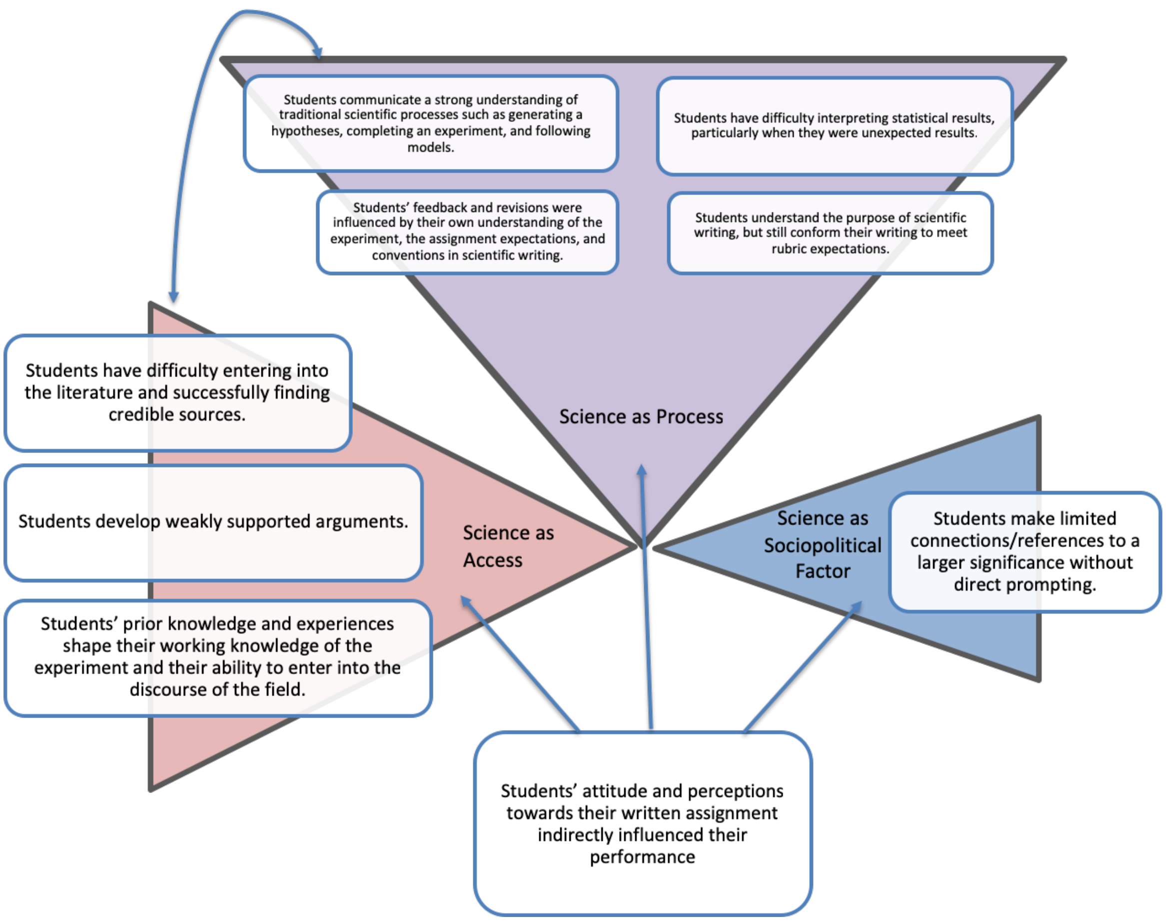

Figure 5.2: The nine themes distributed across the conceptual framework. The proportion of the domain contributing to science literacy is sized according to the number of themes developed around those domains. For example, *students make limited connection/references to a larger significance without direct prompting*, therefore, this domain is smaller than the other

domains. Participants reported generally spending a great deal of time talking about the experiment and completing the assignment/analysis, therefore, *Science as Process* is the largest domain. The last theme did not align with one specific domain; however, it did indirectly affect the performance of the student in each domain. Some students were able to make connections between *Science as Access* and *Science as Process* Domains, represented by the double edge arrow.

In addition to showing an uneven distribution across the three domains of science literacy, *a majority of students were unable to draw connections between all three of the domains, but were able to make one connection between two of the domains.* For example, the most frequent connection made was between *Science as Access* and *Science as Process*. Perhaps a reason why this is the case is because this connection was scaffolded into the manuscript-style writing assignment rubric that students were provided at the start of the assignment. This is not surprising as fading scaffolds have been used in instructional materials, such as rubrics, to help structure students' arguments with success in developing student understanding and cognition (Perkins & Salomon, 1989; McNeill, Lizotte, Krajcik, Marx, 2006). Even though this connection was scaffolded into the rubric, only 75% of the participants were able to explicitly describe the connection between the *Science as Access* and *Science as Process* domains within both their writing and during their interviews.

Those students who successfully made the connection did so in terms of using the primary literature in their introductions to justify their experimental design. One component of the rubric was to introduce the experimental techniques in the introduction as part of their argument (Figure 4.10). One student in particular, Joey, was able to describe how he used his methods to frame the structure of both the results and the introduction citing how he used the methods to align his argument and results. While majority of the students were able to draw the connection between the introduction and the methods, two students, Christie and Jen were not able to demonstrate this connection during either their interviews or within their written manuscripts.

While majority of the students demonstrated a connection between *Science as Access* and *Science as Process,* some students were also able to develop different connections associated with the conceptual framework. For example, Christie, who was unable to demonstrate the *Science as Access* and *Science as Process* connection, was able to use the literature to support a sociopolitical topic in her written artifact. Stacey was able to draw connections between *Science as Access* and *Science as Process*, and *Science as Process* with *Science as a Sociopolitical Factor*; however, she was unable to draw connections between *Science as Access* and *Science as a Sociopolitical Factor*. Lastly, Jen was the only participant who was unable to develop connections between any of the three domains as demonstrated through her interview or writing artifacts.

Apart from connection built between the different domains, each domain had at least one theme present from the cross-case analysis. Each of these themes will be discussed based on their relationship to the framework, including the one theme that did not fit into the framework, but had an external influence on each of the domains.

Science as Access:

The key components of the *Science as Access* domain are being able to enter into the literature and (both physically and conceptually), being able to critically gauge and interact with the primary literature, and developing scientific arguments. These components are tightly aligned with understanding and participating within the discourse of scientific research and scientific writing. Students in this study all demonstrated novice aspects of engaging with the literature and constructing arguments based on that literature; however, their limitations surrounded their lack of discourse.

In science disciplines, argumentation within the manuscripts is critical as it frames the context in which a study is situated and how its findings are situated within the existing literature (Takao & Kelly, 2003; Jimenez-Aleixandre & Erduran, 2007; Garcia-Mila & Andersen, 2007). For example, Hand and colleagues (2003) further suggest that argumentation is a critical component to science literacy, and further suggest that problem solving is not sufficient for science literacy. They argue that argumentation skills are critical to building science literacy and to overall problem-solving capabilities. The findings of this dissertation study suggest that students in introductory biology courses have difficulty not only constructing arguments within their introductions and but also effectively supporting those arguments using the primary literature.

The difficulty constructing and supporting arguments is further compounded by students' inability to properly read primary literature. For example, Takao and Kelly (2003) describe that students require the ability to abstract information from data in order to make scientific claims. In this study the all the students except Anna, discussed the inaccessibility of the results and discussion sections. Students must become "consumers" of scientific texts in order to become scientifically and critically engaged in formal decision making (Sorvik & Mork, 2015). It was not surprising then that the introductory STEM students in this study had difficulty entering into the primary literature as their dominant genre of text in the classroom prior to undergraduate is the textbook (Nelson, 2006).

When exploring student perspective on using primary literature, Verkade & Lim (2016) found that 61% of students reported that they have read most or all of the primary research article when they chose to cite an article. This was not consistent for 88% of the students in this study who often relied on the abstract or the introduction section of the primary article. One possible explanation is the study conducted by Verkade & Lim (2016) was completed with senior level students as opposed to introductory STEM students in a large enrollment course. In comparison to Verkade & Lim (2016), the students who participated in this study have a more limited exposure to the discourse and jargon within the science due to less exposure to disciplinary norms and practices.

Given the less knowledge about and experiences with scientific writing of a first year undergraduate, the students in this study may not have the experience of existing knowledge in how to dissect, analyze, and incorporate their literature into their manuscript-style writing. For example, 88% of the students discussed sourcing their information from the introduction section of the primary literature article. Anna was the only student who discussed sourcing her information from the results and discussion section; this might be explained by her previous experience using literature during her education for her previous English degree. While Anna was able to transfer her literacy skills in terms of finding primary literature, she was still limited by her lack of science discourse in fully engaging with the scientific literature.

In the science disciplines, the convention is to incorporate results and findings from the primary literature into your argument to support your claim and not to borrow background information from other authors (Brownell et. al., 2013; Goldman et al., 2016). However, the students in this study cited the research articles in which they found the cited material as opposed to the original research publication. This is an example of students having the working knowledge that they have to cite information to support their argument, but require further explicit instruction and scaffolding in order to develop the skills aligned to the conventions of the discipline. Furthermore, it demonstrates that students do have limited science discourse skills including dissecting and sourcing information from a primary research article and writing a manuscript style laboratory report (Kondrateve & Ibatulina, 2016).

Because students did not source the information from the correct sections of the primary literature, evidence demonstrating their synthesis of ideas was limited. The results of this study suggest that there was not a cohesive story being told with the literature, but rather, the participants were using the literature in order to meet the expectations of the rubric. Prior research supports this finding. For example, the ability to synthesize literature into an argument might be a limitation of the working knowledge of the individual. Hewings (2004) suggests that first year students tend to write according to the structure that they are familiar with. In the case of first semester freshman, their experience with scientific literature in the form of manuscripts is limited and often comes by way of science textbooks. Furthermore, Hewings (2004) suggest that students do not start to show complex synthesis until their third year. In addition, students' exposure to primary literature can be limited because of the high cost associated with accessing scientific journals and the individual articles (Van Noorden, 2013).

Although students were able to build arguments when they used the rubric to help them write their introductions, they were unable to support their statements with results and conclusions from the prior research studies. It is not unexpected that introductory STEM majors would have difficulty finding applicable literature in addition to having the advanced discourse to fully engage with the text and interpret the experimental findings (Phelps Walker & Sampson, 2013). Every student said they had difficulty finding appropriate literature to include in both his or her introductions and discussion sections. This is an issue that persists throughout undergraduate training (Kardash, 2000).

In summary, the findings of this dissertation further support that student have scientific discourse limitations including using the primary literature to source credible information and using that information to construct arguments. Students were able to construct weakly supported arguments as they were scaffolded and aligned to the assignment rubric. It was not surprising to find that the students were not able to source information from the correct sections of the primary research because the jargon and methodologies are too dauting for an introductory student; however, the findings of this study do support that students have a working knowledge of how to use primary literature, even though that knowledge is not demonstrated in their writing.

Science as Process:

The *Science as Process* domain consists of the process of doing science. Developing hypotheses, carrying out experiments, understanding methodological approaches, analyzing, and interpreting data are all features of this domain. Looking across the eight cases, students demonstrated science literacy in the *Science as* Process domain as represented by four of the nine themes (Figure 5.2). This suggests that students in this study focused their writing efforts and cognitive demand surrounding the *Science as Process* aspect of science literacy.

Across the cases, students most commonly reported spending time focusing on meeting specific conventions of carrying out experiments and scientific process skills, and how to write about them. Furthermore, they focused on how they needed to perform/complete a certain section in their manuscript to address the task at hand; most frequently the focus was onthe demands of the rubric. The K-12 science curriculum supports the development of simple scientific process skills such as generating a hypothesis, following a protocol, and making conclusions (AAAS, 1993; NGSS, 2013; Sullivan, 2008). The results from this study supports that students are the most familiar with these scientific process skills and further suggests that these students are drawing on their prior knowledge and experiences of these skills. For example, all eight participants reported in their reflections that they were confident writing their methods sections. The expectations of a methods section were scaffolded by the provided rubric, and this provided a framework for the content that should be included in this section. Yet while students had perceived confidence in their ability to write their methods sections and the rubric provided scaffolding, all eight students did not incorporate the appropriate level of detail or all of the necessary methods such as the analysis portion.

This finding is similar to what other researchers have argued (Johnstone, Sleet & Vianna, 1994; Gormally, Brickman, Hallar, & Armstrong, 2009). For example, prior research states that novice writers have to discriminate between their declarative and procedural memories regarding their scientific experiments (Johnstone, Sleet & Vianna, 1994). Johnston and colleagues (1994) describe this as a perceptual filter. Johnstone and colleagues (1994) determined that introductory students in a chemistry course have to filter the important details methodologically, as presented in a lab manual, when compared with experts; this results in students heavily relying on the laboratory manual. The students in this study appear to have the same reliance on reporting procedures from the laboratory manual as opposed to having a fully integrated understanding of the laboratory procedures (Johnstone et al., 1994).

Another example of not providing enough methodological detail involves the student not describing how the statistical analysis was conducted. A reason for this absence could be because the statistical analytical approach that was utilized for this lab assignment was not included in the lab manual; rather, students were instructed on how to complete the analysis during the lab. As such, 75% of the students did not include a description of the method for the analysis that they completed, a convention for the methods section of a scientific manuscript. The omission of the analysis section might suggest that the students did not understand the analytical approach with enough detail to report it. Campbell and colleagues (2000) reported that students' notions of the experimental procedures and justification for their experimental approach could be demonstrated in their writing artifact. However, the results of this study are mixed, as 75% of students were able to justify their experimental design in their introductions, but only David was able to use the literature to fully integrate his introduction and methods section by using the literature effectively to justify his methodological decisions.

In addition to relying on the lab manual, according to Johnstone, Sleet, and Vianna (1994) students tend to supplement their perceptual decision-making when writing the methods section. Other researchers find that the task of writing a methods section is often supported by the student's own interpretation of what is important in a methods section (Campbell et al., 2000), and students' attitudes and perceptions towards writing is influential in developing new discourse in scientific writing (Phelp-Walker & Sampson, 2013) The findings of this study support this claim as well. For example, Sean described his process for writing the methods as including the details that he felt were important for others to understand the experiment. Furthermore, Sean discussed during his think aloud that if he did not feel it was important he would not add it to his paper. In fact, six of the eight students expressed similar ideas in stating they only included aspects of the methodology that they found important. The findings of this study indicate then that students' writing was influenced by their perceptions of the integral components of the experiment and on their conceptual understanding of the methodological design.

Another aspect seen across the eight cases involves students demonstrating working knowledge of the conventions of scientific writing from their prior pre-requisite course (BIOL 115). As made evident by the data, this working knowledge was demonstrated differently based on the instruction of the course Teaching Assistant (instructor). For example, during the think-aloud protocol, students who had different TAs had to reconcile their understanding of the expectations of the manuscript assignment and the disciplinary conventions that would satisfy those requirements before they could effectively engage in peer review. Joey and David, for example, had a difficult time consolidating instructor expectation versus what defines a convention during their think-aloud protocol as demonstrated by their discussion:

> *David: I don't know if your TA had you do this differently but we had, she wanted all of our pigments on the same graph.*
>
> *Joey: She said that it didn't matter*
>
> *David: Oh, it didn't matter, ok. Mine said…*
>
> *Joey: Yeah, she said people have problems doing it but I don't, it would probably be hard for me to add them all to one graph.*

David: Yeah no it took me a while to figure out, I just wasn't sure, but if she said that then these chlorophyll graphs look good do you need the total chlorophyll graph?

This would suggest that utilizing a standard curriculum would help facilitate explicit instruction of scientific writing conventions (Brewe, De la Garza, & Kramer; 2013). When incorporating a more standardized curriculum with explicit instruction around scientific writing conventions, students might have not only a clearer understanding of the instructor's expectations for their writing; but also, students might develop a more robust schema of disciplinary conventions of scientific writing.

Apart from developing scientific skills and conventions, students had difficulty with interpreting complex data including the statistical analysis of data, a skill that is not particularly developed prior to post-secondary education (AAAS, 1993; NGSS, 2013; Sullivan, 2008). For example, students in this study demonstrated the ability to discuss what a result meant if the statistical analysis was significant, i.e. they could determine if a p-value was significant or not, thus suggesting that students understood that the p-value was an indicator of statistical significance. More specifically, however, students had difficulty interpreting data that was not statistically significant. Likewise, students could discuss what it means for a result to be significant or not, but they could not explain results that were not what they expected. All 8 students reported confusion when confronted with insignificant data. Throughout all 8 cases, when a result was insignificant (which was often the case with an N of 12 in their experiment), the students attributed the lack of significance to human error. This was another indicator that students had limited discourse surrounding statistical analysis, which is similar to what Kardash

(2000) found: introductory biology students often have difficulty interpreting scientific data and this persists throughout their four years.

In sum, the *Science as Process* aspect of science literacy is not limited to having knowledge and skill of the procedures, analysis of data, and disciplinary conventions. "Procedural understanding, ideas about acceptable laboratory practices, perceptions about the purpose of the investigative task, and the physical and temporal constraints of their situation will influence the investigative behavior of any group of students." (Campbell et al., 2000, p.848). This investigative behavior can also be found in the scientific writing process, as it is an investigative task with complex cognitive demands. This dissertation research suggests that all of these factors come into play in this domain of science literacy.

Science as a Sociopolitical Factor:

The *Science as a Sociopolitical Factor* domain consists of the ability to identify political, social, moral, and economic and connect how those connections have implications in science. S*cience as a Sociopolitical Factor* was domain of science literacy that was the least represented in the data of this study. When specifically prompted about social and cultural impacts, in this study students were able to discuss on the surface level how their experiment was tied to agriculture. For example, all of the students were able to tie their experiment to crops and farming at varying levels of detail. However, only two participants, David and Christie, were able to incorporate literature in their manuscript to effectively demonstrate a broader sociopolitical impact. Both students not only discussed the literature connected to agricultural issues during their interview, but this connection was also demonstrated in their written artifact, thus supporting a connection between the *Science as a Sociopolitical* domain and the

Science as Access domain. Another student, Anna, was able to clearly articulate a sociopolitical topic during her interview, but was not able to demonstrate those connections within her writing.

This finding indicates there is an important missing aspect of students' science literacy as prior research suggests that reading and writing literacies are constrained by sociocultural impacts and in order to achieve science literacy one must have and understanding of their epistemological beliefs and their community (Hand et al., 2003). Other researchers have also examined the connection between sociopolitical aspects and science literacy. For example, Barzilai, Tzadok, & Eshet-Alkalaii (2015) studied how undergraduate science students sourced information about a sociopolitical topic in which they have had a personal experience with and found that readers who did little sourcing of information relied on their own knowledge and those who had a higher number of sourcing activities, relied less on themselves and were able to construct much more elaborate and complex arguments (Barzilai, Tzadok, & Eshet-Alkalaii, 2015). This finding is consistent with this study's findings. For example, in his interview, Sean was able to draw on personal experiences with crop loss in his family's personal garden due to a nutrient deficiency; however, he was unable to develop an argument around a sociopolitical topic in his actual writing.

Despite having instances of personal experiences, cultural experiences, and in some cases, literature support, students were unable to draw connections between how their experiment and experimental techniques and related sociopolitical topics in their writing. In a comparable study exploring first year writing, social implications had little impact on laboratory writing (Campbell et al., 2000). Furthermore, Campbell and colleagues (2000) found that students have difficulty connecting the real-world context in relation to the corresponding laboratory methods. Furthermore, in this dissertation study, while social implications had little impact on the laboratory writing, students' perceptions and attitudes did have an impact on laboratory writing. Like the impact student perceptions and attitudes had on *Science as Access* and *Science as Process*, students linked their overall task of writing the paper with that of the demands of the rubric. If the student perceived that they were meeting the demands of the rubric without a strong sociopolitical connection in their manuscript, then they did not change their drafts even when identifying a sociopolitical connection in their interviews. A reason for this might be because connecting to a sociopolitical topic was implicitly included in the rubric, but not explicitly included. The content was implicit in nature because it is assumed that one would incorporate a larger sociopolitical topic as a part of their broad introduction; this is qualified in the appropriate rational component of the rubric. It is possible that the students did not perceive the importance of including this in their written documents, even though majority of the participants were able to discuss broader implications during their interviews.

In summary, students who were able to make a connection between a sociopolitical topic and their experiment regarding agricultural applications often had an experiential link, like Sean and his garden experience, for example. Five out of eight students were not able to draw connections between sociopolitical topics even though the experiment was directly tied to a topic associated with a Land Grant institution, agriculture. While only two students, Christie and David were able to make a sociopolitical topic connection in their writing; the remaining six students were only able to discuss sociopolitical topics when prompted by the researcher. This indicates that the students are not able to transfer the connection they identified to their written artifact.

Conclusion: Engaging in Authentic Practices:

When students are able to participate in peer review, those students are engaged more authentically in the sociocultural practices of science (Phelps Walker & Sampson, 2013). The students who participated in this study had the opportunity to receive feedback from their lab instructor, a peer outside of the research study, and a peer within the research study during the think-aloud protocol. However, given all of the feedback provided to the students, they were still unlikely to change the structure of their arguments in their manuscript. For example, all of the participants who participated in either the peer review or self-review of their own paper identified weaknesses in their arguments, areas of confusion, or areas of missing details, while only one participant made significant changes to their final writing artifact.

Students were more likely to apply feedback that was provided from their TA; however, the amount of changes made within the writing was directly tied to the number of points lost on the rubric. One explanation to this is that understanding and learning how to edit scientific writing is a difficult concept at any level and even more so when the student is lacking the necessary discourse (Phelps-Walker & Sampson, 2013). This is further compounded by the student's attitude towards writing (Phelps Walker & Sampson, 2013). For example, Sean and Jen were unwilling to incorporate feedback from their peers, both the think-aloud interview feedback and the peer review completed as part of the existing curriculum, as they thought it was not as critical as the feedback received from their instructors. According to Weaver (2006), feedback that is vague is often perceived to be unhelpful and thus not used when editing drafts.

In some cases, the feedback, or lack of feedback received was detrimental to the overall improvement of the paper. For example, Sean had a single paragraph for his introduction in which he developed his argument. Sean stated that since he did not lose points, per the rubric, he therefore felt that there was no need to improve or strengthen his argument even though his argument did not meet the demands of the rubric. Sean did not lose the points because his TA did not grade according to the rubric, thus providing a lack of guidance on how to improve his writing (Weaver, 2006). This finding supports that the attitude towards the assignment affected the writing process and was consistent across all eight cases.

Providing students the opportunity to engage in communities of practice or authentic practices such as manuscript-style writing is critical to developing science literacy (Mason and Boscolo (2000; Cavagnetto, 2011; Auchincloss et al., 2014; Glynn & Muth, 1994). One way to develop and engage students in communities of practice is to talk science, by using scientific jargon and explanations and model/mediate scientific discourse and practices in the laboratory (Kelly & Chen, 1999). Knowing this, the issue then becomes how do we scaffold this disciolinary discourse into the undergraduate laboratory at an introductory level to develop these communities and disciplinary discourse. In this research context, students were engaged early on in authentic disciplinary practices, such as manuscript writing and peer review. The findings of this study suggest that students demonstrated science literacy while engaging in these disciplinary practices at varying levels independent of instructor influence (Phelps-Walker & Sampson, 2013). For example, Stacey and Anna were laboratory partners, yet Stacey demonstrated a stronger understanding of the experimental design and results that developed from her experiment; whereas, Anna demonstrated a weaker understanding of the experimental design and analysis.

By providing students the opportunity to engage authentically in a community of science, not only do students get immersed in the conventions of the field, they receive training to develop the cognitive and metacognitive skills necessary for participating in research and the writing of that research (Reynolds, Thaiss, Katkin, & Thompson, 2012; Zimmerman, Becker, Peterson, Surdick, 2014). Research suggests that engaging students in these communities of practice are critical for both cognitive development and scientific development (Richmond, 1998); these experiences are often limited to small populations of students, most often in their junior and senior years. However, in an attempt to understand how interactions between students and faculty mentors within communities of practice improved authentic research skills and experiences including writing, mentors saw no significant improvement in the ability to use the primary literature or in students' writing abilities (Kardash, 2000). This would suggest that waiting until junior and senior years of an undergraduate program is too late to start developing these cognitive and technical skills.

The findings of this study support that it is possible to start to developing these skills in large introductory courses, thus giving more time for the development of both the cognitive and technical science skills. For example, in this study, students were able to discuss their processes in both accessing the literature and following the conventions for writing; however, they were not able to expertly demonstrate these skills in their writing, thus indicating that there is a basis for developing these skills in introductory courses. Furthermore, multiple students were able to describe the writing process as an iterative process that requires practice to become better. Iterative practice is beneficial for students developing scientific writing skills (Holyoak, 1998). By providing students the opportunity to engage repeatedly in these communities of practice early on in their education, they can develop and hone their skills over the course of four years.

The findings of this study indicate that students are able to demonstrate aspects of science literacy in a manuscript-style writing assignment and its related activities. This work suggests that student do have working knowledge of manuscript writing in science contexts. The working knowledge the students have surrounds the conventions of the scientific writing process and a basic understanding of the experiment. While the students have this working knowledge and can discuss it during their interviews and reflections, they were unable to always effectively demonstrate their knowledge in their writing. For example, students can articulate what they have been taught in class and the expectations outlined by the rubric; however, they were unable to translate all of their knowledge into the writing artifacts. The writing process is a complex process and requires multiple competencies including content knowledge, the procedural process of writing about an experiment, conventional expectations of the field, and the cognitive and metacognitive processes associated with the overall writing process (Gelman & Greeno, 1988; Campbell et al., 2000). These skills consist of accessing and proper utilization of the primary literature, constructing a well-supported argument, and meeting the conventions of each section of the manuscript.

Implications:

Incorporating more authentic writing experiences in the sciences early on in the curriculum can have many benefits. Although introductory students may not have an advanced discourse in the sciences, the results of this study suggest that they do have the ability to not only develop a schema around scientific writing in an authentic space, but also, they have the ability to identify what they do and do not understand when given the opportunity to reflect on their writing. Students reflecting on their writing in this study provided a space for them to articulate what they were confident in and where their frustrations and shortcomings are. This is common among students as they are learning to write (Quitadamo & Kurtz, 2007). The results of this study point to four main implications: (1) students should be engaged in communities of practice in science starting in their introductory STEM courses, (2) authentic writing practices should take place across the undergraduate science curriculum challenging students to develop scientific writing norms, (3) the scientific writing processes (i.e. searching and utilizing primary literature properly, experimental design, writing) should be scaffolded throughout the curriculum and be iterative starting in the introductory major course, (4) incorporate sociopolitical topics should be incorporated into the curriculum to allow students to develop critical connections of social, political, and economic impacts on science.

1. Students should be engaged in communities of practice in science starting in their introductory STEM courses.

Communities of practices allow student to engage as “scientists” in an authentic way. They provide a space in which students can work to develop scientific discourse. Currently, students engage in communities of practice when they participate in undergraduate research experiences; however, these opportunities are limited and often reserved for the best and brightest students (Colabroy, 2011). When provided the opportunity to work closely with faculty student perceptions and attitudes were improved; however, their overall products did not see significant improvement over the course of one undergraduate research experience (Kardash, 2000). This supports the notion that we should be engaging our students early and often to develop these authentic practices.

The results of this study support this as well. All of the students were able to discuss the technical demands of scientific writing based on the prior instruction in BIOL 115. This suggests that there was a schema from which to build from. Where the disconnect arose was when the students had to combine and construct their understandings and translate this new understanding into their writing space, specifically, in the manuscript writing assignment. To combat this cognitive disconnect, students require a space in which they interact frequently in the discourse of the field, continually developing these technical skills (Reynolds, Thaiss, & Katkin, 2012). Participating in communities of practice, such as authentic research activities involving manuscript-style writing in large enrollment courses would provide the space necessary for students to do this.

In addition to providing an authentic space for students to engage in the discourse of science and scientific writing, having students participate in a community of practice improves retentions, students' perceptions around science, and increases engagement in the classroom (Brownell and Kloser, 2015).

2. Authentic writing practices should take place across the undergraduate science curriculum challenging students to develop scientific writing norms.

Incorporating authentic experiences early on in the science curriculum, such as manuscript writing in relationship to an experiment, challenges any student. Challenging a student can lead to increased student engagement and promote excitement amongst the students (Luckie, Maleszewski, Loznak, & Krha, 2004). Students in this study reported their experience in the lab as artificial, assuming that there was a fixed result; however, prior research shows that when students are engaging in a more authentic context, they feel more ownership over their research and the writing process and can rise to the challenge (Colabroy, 2011; Luckie et al., 2004). Students come into college ready to be challenged and it is up to the instructors to create a challenging curriculum.

The standard college curriculum requires a discipline specific writing intensive courses in their junior or senior year (Holyoak, 1998). Furthermore, Holyoak (1998) suggests that the writing necessary for professional development in the sciences is lacking in the curriculum. Writing has been shown to improve critical thinking skills, not only in upper divisional STEM courses, but also in general education biology courses (Quitadamo & Kurtz, 2007). Research has long recommended that students engage in authentic discipline specific writing experiences to develop science literacy. Learning discipline specific writing skills is a foundational skill and should be developed starting in the foundational biology curriculum. This dissertation study shows that this is possible.

3. The scientific writing processes should be scaffolded throughout the curriculum and be iterative starting in the introductory major courses.

The task of scientific writing as a whole can be a daunting task and often frustrating for a writer at any stage. The individual tasks of science writing, such as reading and utilizing the primary literature, or analyzing data, are complex themselves. Like authentic writing instruction, engaging with primary literature as a source of knowledge is reserved for graduate school; but is still a difficult task (Colabroy, 2011). How to effectively approach reading, interpreting, and incorporating literature is a task that should be effectively scaffolded to guide students how to engage and think like a scientist (Quitadamo & Kurtz, 2007).

Hoskins and colleagues (2007) utilized primary research that was written in a series of articles, on the same topic, to help students understand the primary literature. They scaffolded the literature process to have students read easily accessible sections such as the introduction and discussion and then progressed to more to the more complex sections such as the methods and results sections. When this process was scaffolded, students were more successful with understanding the results and findings of the literature, indicating a deeper understanding of the primary literature (Hoskins, Stevens, & Nehm, 2007). While this approach was successful it was incorporated in a junior level course. This type of scaffolding should be incorporated into the introductory course. Again, this dissertation study results support this recommendation.

In addition to scaffolding specific tasks within the manuscript writing space, the writing process itself should be scaffolded as well. Like with the primary literature, there are certain sections of the manuscript that are more difficult to write than others. For example, argument construction is difficult task for writers at all levels. Breaking the manuscript drafting process into manageable sections can promote confidence in the writing process and help students to think the way that scientist by modeling the process that scientist write (Holyoak, 1998). Furthermore, students often can discuss scientific concepts but cannot write about them, scaffolding how to write about scientific processes both at the topic level and the individual paragraph level will better demonstrate to students how to construct scientific arguments (Patterson, 2010) Lastly, the writing process should be iterative. Providing students the space to have repeated attempts to construct one manuscript over the course of the semester is a more authentic experience as scientists write over a series of drafts, not just one draft.

Furthermore, this scaffolding and support can be extended out into the K-12 curriculum. With the adoption of the new NGSS (2013) standards, literacy practices within the discipline are now a part of the curriculum. By scaffolding authentic writing practices into the classroom throughout the K-12 curriculum, we can then start to develop scientific literacy through authentic writing practices prior to students starting their undergraduate education.

4. Incorporate sociopolitical topics into the curriculum to allow students to develop critical connections of social, political, and economic impacts on science.

The importance of improving science literacy across communities is critical due to the impact that science literacy has on citizenship (Feinstein, 2015; Sinatra et al., 2014). By incorporating sociopolitical topics into the existing curriculum, we can foster the connection that there are outside implications and influences impacting science. This connection is critical as sociopolitical topics are incorporated into everyday citizenship within a democracy. For example, citizens who participate in a democratic society will vote for politicians who will make scientific decisions and from there inform policy; this policy can impact things such as air quality, water quality, healthcare, climate change, and other politically charged scientific topics.

Science literacy and citizenship has been discussed as early as the 1920's in the Dewey-Lippmann Debate (Feinstein, 2015). The construct of creating a scientifically literate community is politically charged and has a direct impact on citizenship (Feinstein, 2015) as it involves being able to not only access science information but also make informed decisions regarding politically charged topics. By incorporating these topics into the curriculum and demonstrating them to students, we can develop deeper understanding of topics as they relate to everyday life practices, thus developing experiential links to difficult scientific concepts (Barzalai, Tzadok, & Eshet-Alkalai, 2015) and a more critically developed positions on these topics.

Like with authentic writing practices, socio-politically charged topics can be scaffolded into the curriculum. Students opinions of such topics are often developed based on practice based on personal beliefs and attitudes (Sinatra, Keinhues, & Hofer, 2014, p. 124). By scaffolding the curriculum with sociopolitical topics, students can move from relying on their own beliefs and experiences and move toward supporting their sociopolitical science topic decision making to evidence based.

Summary:

Chapter Five presented a discussion around an exploratory qualitative study exploring the emerging aspects of science literacy in an introductory STEM course. This research focuses specifically on the process of writing an authentic manuscript style lab report, an existing assessment in the course. While research suggests that introductory students lack the discourse necessary to effectively engage in authentic science writing, our results suggest that the students did possess a working knowledge on the conventions of the scientific writing; however, they lacked the ability to effectively translate those conventions into the writing space. Additionally, the study supported the need to start integrating these authentic experiences as freshman enter into their major as opposed to limiting them to undergraduate research experiences often reserved for upperclassmen. There were consistent difficulties across all eight students who participated. These include the ability to access, read, and incorporate literature to form arguments, completing statistical analysis of student data, interpret data, and make connections to larger sociopolitical topics, a problem that persists throughout undergraduate education. By addressing these issues at the beginning of the curriculum, students can start to develop these skills early on, with scaffolding, and have the opportunity to have repeated exposure across the curriculum.

Chapter 6: Dissertation Addendum: Elucidating Connections between Three domains of Science Literacy Framework using a Think-Aloud Protocol Peer Review Activity.

The following chapter is an addendum to the dissertation. It is a practitioner manuscript piece on how to incorporate the think-aloud peer review protocol into the undergraduate biology laboratory. The manuscript discusses the connections that emerged during the analysis and how those connections align with the Science Literacy Framework presented in the dissertation.

Elucidating Connections between Three domains of Science Literacy Framework using a Think-Aloud Protocol Peer Review Activity.

Abstract:

Laboratory practices have shifted to include more authentic activities to improve science literacy amongst undergraduate STEM students; which, is in line with research and policy reforms regarding the development of science literacy spanning all levels of education. A think-aloud protocol was applied to an authentic manuscript style laboratory report during the peer-review process. Students were paired randomly and completed their peer-review while thinking aloud. The peer-review was structured so that each student worked through each section of each other's paper, offering feedback, and answering questions that the student had. This process elucidated the connections that students were able to draw between the three domains of science literacy *Science as Access*, *Science as Process*, and *Science as a Sociopolitical Factor*, but also, the results demonstrated a working knowledge of the domain to be present in order for the connections between the different domains to be present. For example, for students to have a connection between *Science as Access* and *Science as Process*, a student would have a working knowledge of how the literature could be used to justify a scientific method/result. This approach allowed student cognitive abilities and limitations to become

apparent during the think-aloud process, an insight that is not easily found in the written manuscript-style lab report draft.

Introduction:

Science literacy, a term that is used frequently by researchers, has proved challenging to conceptualize definitively, and currently, several diverse definitions exist (DeBore, 2000; Holbrook & Rannikmae, 2009; OECD, PISA, 2000). While it may be difficult to reach consensus regarding the definition of science literacy, researchers do agree that it is critical to developing this disciplinary literacy in the classroom. One approach to developing science literacy is to engage students in authentic science practices.

Over the past 20 years, K-16 educational reform initiatives in the United States and their related policies have pushed to increase the overall scientific knowledge base of US citizens (Association for Advancement of Science (AAAS), 2011; Howard Hughes Medical Institute (HHMI), 2000; President's Council of Advisor on Science and Technology (PCAST) 2010, 2012)—in other words, to increase science literacy. These reform initiatives and policies involve engaging K-16 students in authentic disciplinary practices.

In response to achieving the goal of creating scientifically literate students, researchers have developed curricular changes spanning the K-16 classroom, including the creation of Next Generation Science Standards (NGSS 2013). The new standards are designed to bring authentic scientific practices into the classroom by integrating these practices with specific science content knowledge and scientific explanations. Additionally, the new standards allow students to engage in scientific inquiry and argumentation.

This push for incorporating authentic scientific practices is also seen at the undergraduate level; however, it is often reserved for upper-level students who have already self-selected into the major. For example, scientific writing/communication is often studied in small journal club seminar courses with low enrolment at the 300-400 level (Brownell et al., 2013). However, it has been suggested that engaging introductory undergraduates in authentic STEM practices not only improve retention of students but also increases enthusiasm for science (Auchincloss et al., 2014).

While we know that entering undergraduates in introductory-level science courses have not necessarily developed the discursive practices to engage in authentic disciplinary research practices (Hewings, 2005), this does not mean that they cannot engage in authentic research in meaningful ways. Authentic practice in the introductory undergraduate classroom might be used not only to address the legislative concerns of creating a scientifically literate society but also provide a context in which to examine the current state of science literacy among undergraduate students in the introductory biology laboratory.

To begin to understand the relationship between science literacy and authentic practices, I redefined science literacy by consolidating and reconceptualizing existing constructs of science literacy. This reconceptualization consisted of drawing on Hurd's 25 criteria (1998) that a scientifically literate person would possess; and resulted in the formation of three domains, *Science as Access*, *Science as Process*, and *Science as a Sociopolitical Factor*. In addition to the formation of the three domains, I overlapped these domains with the idea that science literacy is multidimensional (Miller, 1998). The resultant definition of science literacy emerged (see Figure 6.1 for model). *Science as Access* is defined as an individual's ability to access scientific information not only in terms of physical access but also conceptual access and to critically use that information to structure a scientific argument. *Science as Process* is defined as the ability to engage in scientific practices to construct scientific understandings. *Science as a Sociopolitical Factor* is defined as the individual's ability to understand and recognize that science as social, cultural, political, economic, and moral implications.

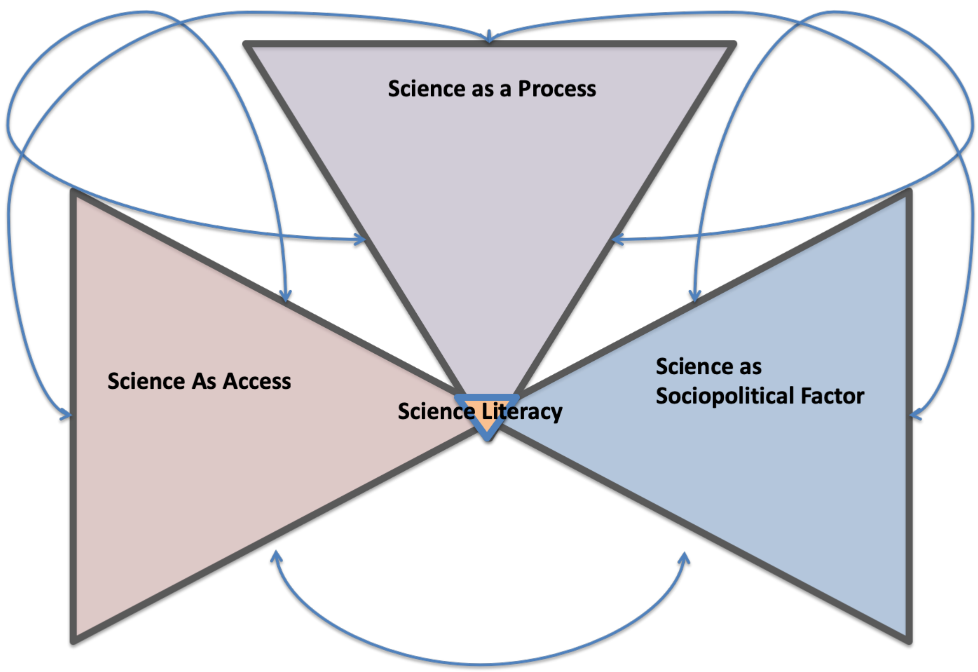

Figure 6.1: **Science Literacy Framework:** A proposed multidimensional approach to demonstrating science literacy. Science literacy is a construct that is heavily influenced by each of the three domains, *Science as Access*, *Science as Process*, and *Science as a Sociopolitical Factor*. The connections fostered comes from working knowledge within the domain and an understanding of how one domain may influence another.

This model of science literacy also supports the claim that there is no one path to becoming scientifically literate, but instead multiple paths that are not linear but circuitous

(Figure 1). What makes this model unique is that it not only draws on classical aspects of science literacy but also refocuses science literacy to highlight the connections that emerge between the three domains of science literacy where students are developing connections and fostering a deeper scientific understanding. In this study, this model (referred to as the Science Literacy Framework) was applied during the peer review process to explore emergent connections between the domains of science literacy.

Peer review is an authentic practice that exists in research practice and the undergraduate biology classroom (Thiry, Laursen, & Hunter, 2011). Not only is it an authentic practice, but peer review has also been shown to improve students' scientific reasoning skills including critiquing and evaluating the quality of scientific claims and scientific practice, content knowledge (within the domains), and writing skills (argumentation) (Timmerman & Strickland, 2009). Research has shown that peer review can be completed in a variety of ways, including written, verbal, or online (Brieger & Bromley, 2014). Brieger & Bromley (2014) also suggested that students who were able to give and receive a peer review submit stronger manuscripts, had increased confidence to interpret and incorporate results and revise more fully.

In the undergraduate laboratory, peer review is typically done individually in a written format for traditional laboratory courses where students receive a manuscript draft and provide written feedback based on the rubric provided (Hollenbeck, Wixson, Geske, Dodge, Tseng, Clauss, & Blackwell, 2006; Brownell, Kloser, Fukami, & Shavelson, 2012). While it is known that peer review is an opportunity to improve scientific reasoning skills, when it is performed in isolation, educators miss the opportunity to identify cognitive dissonance when only reviewing the final manuscript draft. Identifying this cognitive dissonance could provide the instructor the opportunity to tease apart concepts that have been mastered versus concepts that students are still struggling to master. Furthermore, populations of students are not one size fits all and identifying the cognitive dissonance further allows the instructor to shift the curricular goals and align them with the needs of the student population.

To identify cognitive dissonance that may not be readily seen in a written manuscript, a think-aloud protocol can be applied. The think-aloud process is defined as "a classical introspection in which a person analyzes their thought processes" (Jääskeläinen, 2010, p. 371; van Someren, Barnard, & Sandberg, 1994). This method highlights the students thought process as they actively work through their peer review and can elucidate how students are constructing knowledge but also highlight cognitive dissonance that can be addressed either by the peer or the instructor. Another affordance to this method is that it does not disrupt the cognitive structure of the cognitive task at hand but is dependent on cognitive load, meaning that it has to occur close to the instance being investigated for it to be the most effective (Jääskeläinen, 2010). More specifically, the think-aloud protocol could be used to gain insight into the elements of science literacy that would otherwise remain hidden by only looking at the written artifacts; again, identifying cognitive dissonance within the framework could provide the space to tease apart which aspects of science literacy need to be developed further. Furthermore, think-aloud protocols have previously been used in research to engage students in the authentic practice of peer review (Graff, 2009), thus providing a means for exploring aspects of science literacy in authentic research contexts.

To apply the Science Literacy Framework (described above) to the introductory undergraduate laboratory, this exploratory study employed a think-aloud protocol utilized during the peer-review process of an authentic manuscript style writing assignment. In order to understand what aspects of science literacy emerged as introductory students worked through writing an authentic manuscript style writing assignment, the think-aloud peer review process was situated after students had completed a rough draft of a plant nutrition experiment manuscript.

Methods:

Participants and Assignment. The four participants were recruited from two summer sections of an Introduction to Physiology (100 level) course at a land-grant institution in the Mid-Atlantic region of the United States. This course included a laboratory section in which disciplinary-specific instruction in biological writing, including rhetoric and conventions, was briefly (10-15 minutes per section) reviewed in the course. As part of this course, students worked in small groups consisting of 2-4 students that remained consistent for the duration of the course. The lab instructor led a class discussion about the process and product of writing the different sections of a manuscript-style laboratory report (e.g., the structure of an introduction and the logical topics that should be included in each section). Students wrote a total of two manuscripts; this research focuses on the second manuscript since it involved a more authentic writing approach and was less guided than the first laboratory manuscript writing process. In addition, students discussed each section of a laboratory manuscript-style writing assignment (e.g., introduction, methods, results, and discussion) before the writing assignment this research involves. Furthermore, students completed guided library searches in the laboratory in order to support skill development around finding relevant literature of the biology concept being investigated in the lab setting.

The writing assignment used in this study was introduced in the third week of the six-week course and was considered to be the summative laboratory assignment for a plant nutrition module. Each component of the assignment was described in detail to the students, and an evaluation rubric was provided. This assignment aligned with an inquiry-based curriculum (Weaver, Russell, & Wink, 2008) module on plant nutrition and required students to generate research questions, form hypotheses, develop the experimental design, including defining variables, and carry out their experiment. It culminated in the manuscript-style writing assignment reporting on the full experiment. More specifically, this module started by having small groups of students write a mini grant-style proposal designing a study where they explored one macronutrient required for proper plant growth and development. This small groups' writing assignment required the students to frame the significance (or broader context) for studying their particular nutrient. Students voted on the project that they thought was the most interesting, and the entire class then carried out that experiment.

Think-Aloud Interview. A think-aloud protocol was used to gain access to how the participants revised their manuscripts and provided feedback to their peers. This interview was structured similar to a standard peer review where students exchange papers and provide feedback in line with the provided rubric with the goal being to improve their rough manuscript draft. The peer review is done randomly and the writer is removed from the reviewer and only given the feedback through written corrections. As a part of the existing curriculum, students completed the standard peer review. In this study, students were asked to think out loud verbalizing their entire thought process while they conducted an additional think-aloud peer review. To prepare participants for this non-traditional interview structure, I asked students to think-aloud as they counted the number of windows in their house. This approach has been used to acclimate students to thinking aloud as they count, a task normally completed silently. Another training method that was used was to solve a simple algebra problem while thinking out loud. These processes introduced the students to thinking aloud, a process that does not naturally occur (Anders Ericsson & Simon, 1998).

After the participants practiced the think-aloud structure through these tasks, the think-aloud interview was conducted around their revision process of the rough draft. The rough draft of the plant nutrition lab was assigned following the completion of data collection. Students were tasked with completing the data analysis and writing a complete manuscript draft following the provided rubric guidelines. The assignment was to be completed as an individual writing assignment. The average length of the paper was ten double spaced pages. Students brought a physical copy of their manuscript with them to the peer review think-aloud interview along with their computers. The peer-review think-aloud interviews occurred outside of the classroom and were not a course requirement. Before completing the peer review think-aloud interview, students completed a written peer review in class of another student in their introductory laboratory class. None of the students who participated in this study had previously reviewed their partner's paper. Students had the opportunity to receive additional feedback from the lab instructor if they submitted their rough drafts before the final submission. The standard grading protocol for the rough draft assignment was that each student would be provided a grade (125 points) and feedback based on the rubric from their instructor, their grade was multiplied by .25 to serve as their rough draft grade.

In this study, each student served as a reviewer and a reviewee in the same think-aloud peer review session. The first student was responsible for peer-reviewing the other's manuscript draft, and after the first peer review, the pair switched roles. During the think-aloud, students had a copy of the rubric as a reference. Performing both roles allowed the student to gain the benefit of both providing and receiving a peer review. The students were not limited in time to complete their peer review; on average, each student's paper took approximately 45 minutes to complete. The think-aloud protocol was voice recorded. The students were not instructed to write their feedback out to prevent an increase in the cognitive demand of the task. During the interview, students receiving the feedback made revisions in real-time during their peer review think-aloud session. If the student was able to address the feedback provided by the reviewer, this suggested that they had the working knowledge to address the cognitive dissonance; and were able to address the missing components of the manuscript-style writing. This parallels with science literacy as a scientific literate person may not have perfect drafts, but they do have the ability to correct and edit that draft.

As the researcher, I acted as an observer as the process occurred, and I interjected with a question about why they were doing a certain revision or whenever I noticed they were not thinking aloud through the revision process. My interjections were only meant to stimulate their thinking aloud, not to direct their revision process; however, there were circumstances where I interjected to address severe dissonance that I did not believe that the other participant could address.

Results:

The peer-review think-aloud demonstrated that the student's ability to make connections between the three domains of science literacy discussed earlier was dependent on their knowledge within a specific domain of the Science Literacy Framework. For example, if a student demonstrated weak *Science as Process* skills during the think-aloud, then it was unlikely that they would be able to make a strong *Science as Access* and *Science as Process* connection. Likewise, if students had no mention of a domain, for example, *Science as a Sociopolitical Factor*, then there were no connections made.

Anna and Stacey: Anna and Stacey were lab partners who worked together to propose and carry out their experiments. The level of feedback they gave each other during the think-aloud provided insight into the amount of understanding they each had for each of the domains in the Science Literacy Framework. For example, Stacey provided grammatical, structural, and content revisions during her think-aloud peer-review with Anna. Yet, Anna relied on only structural and grammatical corrections during her review. This reliance on formatting and grammar suggested that Anna had limited working knowledge of the *Science as Process* domain because she did not provide feedback to her peer that included the experimental design, the analytical approach, or an understanding of the statistical results; rather, Anna relied on her peer to help her understand these aspects of the experiment. These differences in the students' peer review feedback highlighted aspects of both students' science literacy as well as whether and how they were making connections across the three domains of the Science Literacy Framework. I discuss this more next.

The data suggested that working knowledge within each of these domains was critical for the students to be able to navigate scientific writing but also integral in highlighting connections between the domains. For example, Anna and Stacey were lab partners who completed the same experiment, Stacey demonstrated a strong understanding of the *Science as Process* domain and a working knowledge of *Science as Access* domain as evidenced by her interview responses

> "The *Brassica rapa*, it grows really quickly, so you can see stunted growth, so the chlorosis and the quick time without having to wait for the plant to grow fully."

Here, Stacey was using the literature about her plant species to justify why it could be a model organism for her experiment. Because Stacey had a working knowledge of both domains, she demonstrated the ability to draw connections between the domains. For example, Stacey was able to discuss her experimental design and use literature to support her decisions and then also explain some of her results in terms of expected outcomes. (It is important to note that Stacey did not navigate the *Science as Access* domain at the expert level and often discussed difficulty navigating the literature, but she was able to use current knowledge to find the resources necessary to draw connections between the literature and her experimental design at the introductory level).

On the other hand, Anna had a difficult time navigating the *Science as Process* domain as evidenced by her inability to discuss the experimental design, analysis, and interpretation of the data:

> Anna: A higher level of chlorophyll means the plant is healthier?
>
> Stacey: Yeah, a higher level of chlorophyll concentration, but it does matter which chlorophyll it is, a, b, or carotenoids. I think it is just different types of light so.
>
> Anna: Ok, because the only reason that I am asking is why would it be important to figure out this? I did not know, so these three were measured, and then there are these three averages for chlorophyll, oh ok.

Even though Anna drew on her prior knowledge to navigate the *Science as Access* domain, her inability to navigate the *Science as Process* domain limited her ability to make connections between the two domains, this excerpt highlights that Anna is lacking an understanding of the experimental design and the dependent variables that were being measured (regardless of the experiment that the student chose to carry out, photosynthetic pigments were a required methods that all students were instructed to incorporate into their experiment). Interestingly enough, while Anna was unable to draw connections in her writing, she was able to identify where Stacey was making connections between *Science as Access* and *Science as Process,* or more specifically, the literature and the experiment and the results to the literature creating a two-way connection. So, this suggests the peer-review process could support Anna in making connections between the domains of science literacy that she may not have made otherwise when focused only on her own manuscript.

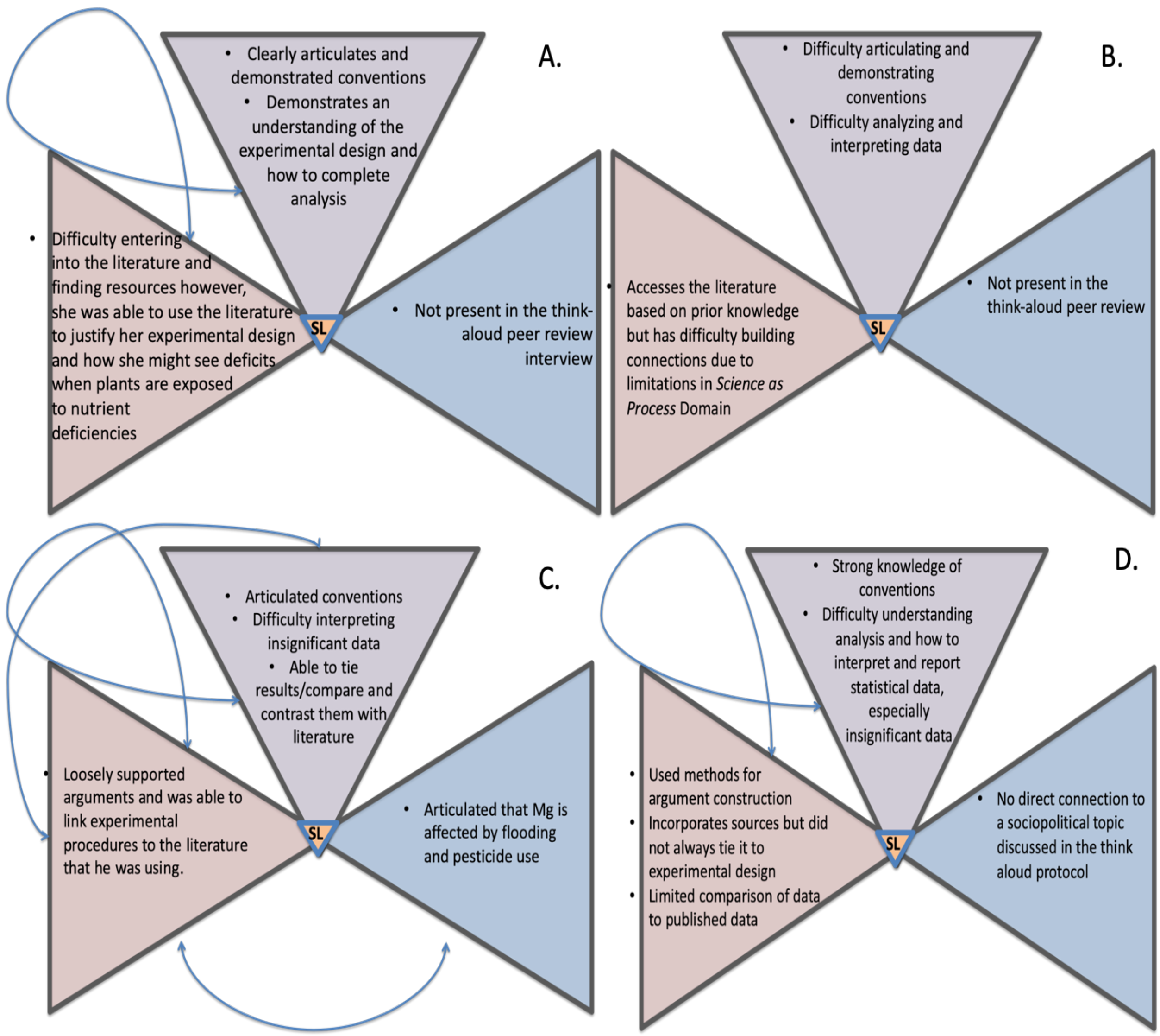

Figure 6.2. **Depictions of Science Literacy per participant based on their think-aloud protocol.** A. Stacey, B. Anna, C. David, and D. Joey. The connections are demonstrated by a bi-directional arrow. If a student was able to make the connection from one domain to the next and then back to the original domain, then it is represented by two bidirectional arrows; for example, *Science as Access* to *Science as Process* to *Science as Access*. If a student was not able to draw connections between the domains, there were no arrows present between those arrows. These connections could be made at different points in the think-aloud peer review writing process, including the introduction, methods, results, and discussion (Red= *Science as Access*, Purple=*Science as Process*, Blue= *Science as a Sociopolitical Factor*, Orange= Science Literacy).

David and Joey: Joey and David were not lab partners but were in 2 different sections of the Introductory Physiology laboratory. Unlike Stacey and Anna, both David and Joey were able to demonstrate during the think-aloud peer review process an understanding of the need to develop connections between the domains of science literacy (Figure 6.2). Furthermore, they were able to demonstrate that the connections across the domains that were being made were pertinent to the development of the arguments that they were making within both the introduction sections and the discussion sections of their mansucripts:

> David (to Joey): In your objective hypothesis, I guess it could be a little more detailed.
>
> Just [include] what exactly with stomatal density and chlorophyll a, b, and carotenoids or something like what it is looking at, it was just the first time that you included these in the introduction.
>
> Joey: So, you think I should have a paragraph in the introduction explaining the methods?
>
> David: Maybe not an entire paragraph, bit some more before that like stomatal density, as more stomata are present, the healthier the plant is, that might be a good idea so that it does not just come out of nowhere.

Here, David recognized a need for more information in order to establish the connection between the literature and the experimental design, thus demonstrating knowledge of the connection between *Science as Access* and *Science as Process*. While there was more information needed to establish this connection, Joey was also able to demonstrate where there would be connections between the domains within David's writing.

> Joey (To David): Your techniques of the work (experiment) were very specific, and it told me basically what you are measuring, and it goes to your rational and objective point.

The strongest connections between the domains demonstrated by both Joey and David were between *Science as Access* and *Science as Process*. They were able to develop the connection verbally while they were working through their think-aloud peer review.

By allowing Joey and David the opportunity to talk about this process aloud, I was able to see developmental areas of their science literacy that one would not be able to elucidate from a written artifact. For example, the connections that David and Joey were making were not sophisticated, but rather they demonstrated a developmental process that could allow for follow up in the curriculum or even dedicated curriculum resource and time. For example, both Joey and David to recognize in some spaces where they should be including primary research; however, they do not discuss including more experimental findings to support their claims, rather, they discuss including sources to support their claims. This developmental process could easily be addressed by spending more focused curricular time reading, summarizing and incorporating primary literature.

Providing Joey and David the ability to complete the think-aloud peer review gave them space and opportunity to highlight their cognitive needs while working through a process that they are familiar with, peer review. Furthermore, as seen in the following excerpt, this approach provided me (as the researcher) insight into particular areas of concerns or confusion from the students' standpoint:

> David: I do not know if your TA had you do this differently, but we had…she wanted all of our pigments on the same graph.
>
> Joey: Our TA said that it did not matter
>
> David: Oh, it did not matter
>
> Joey: Yeah, she said people have problems doing it. It would probably be hard for me to add them all together all on one graph.
>
> David: Yeah, it took me a while to figure out, I just was not sure, but if she said that then these chlorophyll graphs look good. Do you need the total chlorophyll graph?

One particular instance where cognitive needs were demonstrated during the think-aloud versus the written manuscript was Joey's description of his connections. For example, in his actual writing artifact (his rough draft), Joey did not display any connections between the *Science as Access* and *Science as Process* domain in his actual writing artifact, but during the think-aloud session he was able to discuss these specific connections with his think-aloud partner verbally.

> Joey (Responding to Feedback): basically elaborate on the part of how I said something about the hypothesis and stated that none of the comparisons were significant and then describe the relationship between magnesium deficiency and chlorosis can be made.

Here, Joey showed an understanding of why an individual would and how they might go about incorporating literature into his introduction and discussion to not only build his argument but also to support his experimental design. This suggests (like with the example of Anna above) that the think-aloud peer-review process could support Joey in making connections between the domains of science literacy that he may not have made otherwise when focused only on his own manuscript.

In this think-aloud peer review session, David, on the other hand, had a strong understanding of the domains and the connections that he was building between the domains. For example, David demonstrated a two-way connection between the *Science as Access* and *Science as Process* and *Science as Access* domains

Joey: David elaborated on the part where he said something about the hypothesis and then stated that none of the comparisons were significant and then he discussed the relationships between magnesium deficiency and chlorosis

Here, Joey is discussing how David was able to talk about his hypothesis in the discussion, relate that to his experimental findings and then compare and contrast those findings to other literature to support a link between magnesium deficiency and chlorosis. David also demonstrated a connection between the *Science as Access* and *Science as a Sociopolitical Factor* domain. Additionally, David was able to draw on connections between the domains that were present in Joey's writing and also identify where those connections were missing.

David: Then don’t worry about it um I think for your last sentence, the objective/hypothesis um I guess it could be a little bit more detailed like um, just about what exactly with stomatal density and chlorophyll a, b, and carotenoids or carotenoids or something like what it is that looking at. It was just the first time mentioned in the introduction

Joey: So you think I should have like a paragraph explaining all of the methods?

David: Maybe not a paragraph but just a little bit before that like stomatal density as more stomata is present like healthier the plant is and then with like the pigments like more pigmentation the healthier the plant is so that might be cool just to like so it doesn’t come out of nowhere but like I don’t know it’s like, it’s a really, really good introduction, yeah but maybe just like talking about like what exactly the stomata and pigments do. And then what did you do, you compared height for phosphorous deficiency? Is that what you did?

Joey: We did height, number of leaves,

David: Height, number of leaves ok

Joey: Stomata and pigments

David: Pigments cool.

Joey: Yeah

David: And I would just maybe say, maybe like have a sentence in there saying like the higher the plant like the taller it is and the more leaves could indicate plant health maybe have like a citation for that or something, I think that might help make the objective a little clearer but other than that I think it is a really good introduction.

In addition to suggesting that Joey should add background information supporting his experimental techniques in his introduction, David was suggesting that David also offered Joey a perspective on where he could add a connection between *Science as Process* and the *Science as a Sociopolitical Factor* domain.

An additional layer of complexity that emerged during the think-aloud involved students trying to negotiate the expectations of the assignment. During the think-aloud peer review, when David and Joey started each new section of the manuscript style writing assignment, they had to negotiate the conventions and expectations that both of their instructors had for each section in order to determine best how to peer review. This is a unique feature of the think-aloud because the instructor can see in real-time how the students are applying the conventions and when there is a misalignment between expectations and conventions or vice a versa.

Discussion:

The think-aloud peer review process highlighted that students were able to make some connections between the domains of science literacy, but not others. For example, while students were expected and instructed to draw connections between their experimental design and results and a larger societal/broader context topic, none of the participants were able to make this connection. The connections between *Science as Process* and *Science as a Sociopolitical Factor* or *Science as Access* and *Science as a Sociopolitical Factor* was rarely supported in the students' writing and only discussed once during the think-aloud peer review process amongst all 4 participants. David was the only participant who was able to draw this connection between *Science as Process* and *Science as Sociopolitical Factor* during the think-aloud session.

The most distinguished connection elucidated using the think-aloud peer review process was the *Science as Access-Science as Process-Science as Access* connection. This connection was scaffolded by the assignment rubric in relation to the requirement to support claims in the introduction and discussion sections using the primary literature. The students heavily relied on the structure of the rubric when writing their manuscript drafts. Because of this, students understood that they needed to use the literature and incorporate it into their introductions and discussion sections. Incorporating literature is a component of *Science as Access* and the connections between *Science as Access* and *Science as Process* are often related. For example, literature can be used to supporting experimental techniques and previous experimental findings in the introduction. Furthermore, literature can be used to compare and contrast literature to the current finding of the students' experimental findings and conclusions in the discussion section of the student's manuscript style lab-report draft.

While the connections between the domains of the Science Literacy Framework are scaffolded by the rubric, the think-aloud peer-review process allows instructors to not only identify students’ areas of uncertainty or strengths within each domain of the Science Literacy Framework, but also to see where students are drawing the deeper connections between each of the domains. It is unreasonable to think that one instructor could sit through multiple paired think-aloud peer review sessions in one lab period; however, students, after appropriately trained, could record their think-aloud peer reviews and submit it for instructor review. This process would take approximately 1.5 hours (~45 minutes per student). By reviewing the recordings, the instructor would then have the ability to identify students’ areas of uncertainty or strengths and modify instruction. Adapting in this manner would allow instructors to align scientific laboratory instruction along with the needs of the students. This method can also allow both instructors and students to identify areas of the framework that are not addressed. For example, *Science as a Sociopolitical Factor* as a domain was only addressed in one pass during the interview by one student, and since there was no mention of the domain, there were no connections made between the *Science as a Sociopolitical Factor* domain and the other domains. The insight provided to the instructor from the think-aloud peer review process would allow them to address why students are not incorporating certain content, such as sociopolitical topics into their writing and help instructors to align the curriculum to address such topics. Furthermore, understanding where the gaps in knowledge exist in the students current knowledge and understanding, will help to foster science literacy development in the curriculum.

In addition to allowing both students and instructors to identify weaknesses and strengths, the think-aloud protocol peer-review also allowed students a safe space to work with a peer. While the students were working through their peer review, they were able to work and edit in real-time. An additional affordance of this approach also included students in asking for clarification of an edit as opposed to having deciphered what the reviewer meant. Furthermore, this methodology allowed students to ask for further clarification from their peers if they were confused or just having a difficult time understanding a particular section of that paper. Lastly, the participants in this study often applied the feedback that they were giving their peer to their paper; thus, suggesting that the think-aloud peer review provided a space for meta-cognition to occur.

Applying non-traditional methods of peer review in the undergraduate biology laboratory, such as the think-aloud interview, can help elucidate the connections that are made with the Science Literacy Framework presented here. When applied to the introductory biology laboratory, students felt safe to ask their peers questions, as evidenced by their interview transcripts. The think-aloud also allowed me as the researcher to gain a deeper understanding of their knowledge within each domain and the knowledge demonstrated between each domain, as evidenced by the connections that the students were making. Furthermore, students presented difficulties making connections between *Science as Access* and *Science as a*

Sociopolitical Factor and *Science as Process* and *Science as a Sociopolitical Factor*. The instructor would want to be careful not to lead the student to that connection. The instructor can interact with the students, but should keep their line of questioning to process questions such as: Why did you incorporate/not incorporate that edit? How did you do that? Why did you do that? The reviewer/reviewee should be answering the questions regarding their process for writing.

In conclusion, the think-aloud protocol peer-review provided the space for students to not only peer-review each other manuscript style writing assignment, but it also provided them a space to raise questions that they may have about a particular domain or writing convention and address that concern in real-time. Furthermore, the think-aloud elucidated connections that were made between each of the domains or the lack thereof. In comparison to traditional peer-reviews, which are often done in isolation, the think-aloud provides the opportunity for the student to ask questions, reflect on their writing process, and allows for peer advice in real-time.

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Appendices

Appendix A: Hurd's (1998) 25 Criteria:

Science as Access	Science as Process	Science as Sociopolitical Factor
Distinguishes experts from the uninformed	Senses the way in which scientific research is done and how the findings are validated.	Knows that science in social contexts often has dimensions in political, judicial, ethical, and sometimes moral interpretations.
Distinguishes theory from dogma, and data from myth. Recognizes that almost every facet of one's life has been influenced by science or technology.	Recognizes the cumulative nature of science as an "endless frontier"	Uses science knowledge where appropriate in making life and social decisions, forming judgments, resolving problems, and taking action
Distinguishes science from pseudoscience such as astrology, quackery, the occult, and superstition	Knows how to analyze and process information to generate knowledge that extends beyond facts.	Recognizes scientific researchers as producers of knowledge and citizens as users of science knowledge
Recognizes that science concepts, laws, and theories are not rigid but essentially have an organize quality, they grow and develop; what is taught today may not have the same meaning tomorrow.	Recognizes when a cause and effect relationship cannot be drawn. Understands the importance of research for its own sake as a product of a scientist's curiosity.	Recognizes gaps, risk, limits, and probabilities in making decisions involving a knowledge of science of technology
Distinguishes evidence from propaganda, fact from fiction, sense from nonsense, and knowledge from opinions.	Recognizes when one does not have enough data to make a rational decision or form a reliable judgment.	Knows that science problems in personal and social contexts may have more that one "right" answer, especially problems that involve ethical, judicial, and political actions
Views science, social and personal, civic problems as requiring a synthesis of knowledge including natural and social sciences	Recognizes that scientific literacy is a process of acquiring, analyzing, synthesizing, coding, evaluating, and utilizing	Recognizes that our global economy is largely influenced by advancements in science and technology

	achievements in science and technology in human and social constructs	
Recognizes there is much not known in a science field and that the most significant discovery may be announced tomorrow	Recognizes that the immediate solution of science social problem may create a related problem later	Recognizes when cultural, ethical, and moral issues are involved in resolving science-social problems
Recognizes that short- and long-term solutions to a problem may not have the same answer.		Recognizes the symbiotic relationships between science and technology and between science, technology, and human affairs
		Recognizes that science-social problems are generally resolved by collaborative rather than by individual action
		Recognizes that the immediate solution of science social problem may create a related problem later

Note: It is interesting that according to these criteria that the emphasis of science literacy is guided by *Science as a Sociopolitical Factor* for majority of the criteria; however, most people tend to discuss science literacy in terms of *Science as Access* and *Science as a Process*.

Appendix B: Pre-Interview Questions:

Q1**:** I am going to show you a model. This model is my model of science literacy as I see it. Please describe what the model looks like to you and how this model might have been informed through experiences that you may have had in your life.

Q2: How in your life have these ideas been supported or not supported?

Appendix C: Metacognitive Reflection Prompts 1 and 2:

Reflection 1: Please reflect on each section (introduction, methods, results, and discussion) of drafting the rough draft. Please focus on trouble spots when writing or limitations in the writing process and also areas where you felt strong in the writing process.

Reflection 2: Please reflect on the revision process and how it aided/did not aid your writing process, more specifically, identify areas of uncertainty and if you understand all of the changes that were suggested to be made.

Appendix D: Think Aloud Protocol:

	In the writing process, how do students use reflection and revision to effectively communicate and build science literacy?			
Sections of Manuscript Draft	Introduction (15 minutes)	Methods (12 minutes)	Results (13 minutes)	Discussion (15 minutes)
	Open-Ended Follow-Up Probing Questions			
	Why did you delete those sentences? Why did you add that study to your argument? Why did you structure your argument that way? Why did you or didn't you decide to utilize the feedback? How does your introduction fit the demands set forth by the rubric? Could you explain how your literature supports your argument? Why are you making that particular change (specify	Why did you delete those words/ sentences? Why did you choose to include the level of detail that you did? How does your methods section fit the demands set forth by the rubric? Can you explain how your methodological approach can support your hypothesis? Why are you making the change? Why did you or didn't you decide to utilize the feedback?	Why did you delete those words/ sentences? Why did you choose to represent your data that way? Why are you using the statistics that you are using? How does your statistics and p-value support/not support your hypothesis? Why are you making the change? Why did you or didn't you decide to utilize the feedback?	Why did you delete those words/ sentences? How do your results relate to you hypothesis? (Do you results support or reject the hypotheses?) How do you address conflicting results? How do you address conflicting results within the literature? Where do you source your citations? How do your results link back to the broader significance you introduced in

	based on context)? Where did you find that source? How could you alter the transitions so that your argument could flow better? How does your argument fit into a bigger significance outside of the scope of the experiment?			the introduction? How would you use the literature to interpret your results? Why are you making the change? Why did or didn't you decide to utilize the feedback? Why did you ask the follow-up question you did for the next steps? How do the limitations of the study affect your overall understanding of the experiment?

Appendix E: Stimulated Recall Interview Protocol:

One of the goals in undergraduate biology education is to help students build science literacy.

We are going to talk about your paper today, before we start,

Q1: Can you tell me what it means to be scientifically literate?

Q2: How does your writing show science literacy?

Introduction Questions:

Q3: How does your final writing assignment demonstrate a connection to larger societal issues?

Q4Can you tell me your process for writing your introduction?

Q5: Where do you look for sources in the literature?

Q6: When you read a primary source, what part of the paper do you look for information?

Q7: How do you evaluate a source for credibility?

Q8: How did you use your sources to construct your argument and form your purpose statement/hypothesis?

Methods:

Q9: Now, can you just tell me how you wrote your methods section?

Q10: Did the methods change from the proposed methods, if so, how and why?

Q11: Why do you think these methods support the argument that you constructed?

Results:

Q12: Can you tell me how you wrote about your result?

Q13: Was there anything surprising or unexpected about your results?

Discussion:

Q14: Please tell me how you wrote your discussion section?

Q15: Can you explain/show me the logic between your argument, methods, and results in the discussion?

Q16: Why did you structure the discussion the way you did?

Q17: Why would you cite sources in the discussion?

Q18: Is there a competing argument with your results?

Q19: If not, are you sure? Did you look them? (If yes, why this and why that ask about competing argument).

Q20: How did you compare your results to the existing literature? Both that which agrees or disagrees.

Q21: Can you tell me about your search process and what you do to be sure?

Q22: How does your final writing assignment demonstrate a connection to larger societal issues?

Now that we have gone through your paper, lets revisit that first question.

Q23: How does the writing process that you just described in this paper support your science literacy.

Q24: Now that we have gone through this interview, can you give me your definition of science literacy?

Appendix F: Course Outline for BIOL 117: The outline of assignments in the BIOL 117 laboratory.

BIOLOGY 117 COURSE TOPICS AND ASSIGNMENTS

Please see eCampus for an up-to-date version of the schedule, including dates and holidays.

Lab	Date	(Fish) Phylogenetics	Plant Growth and Physiology	Comparative Physiology	IC	H	Q
1	Jan 9–13	■ ***In-Class:*** Clade race ■ ***Homework:*** Phylogenetics questions—due wk. 2 ■ ***Quiz 1***			10	35	20
Jan 16–20		Martin Luther King Jr. Day—No Labs					
2	Jan 23–27	■ ***In-Class:*** Trait coding ■ ***Homework:*** Focus Question on Fish and Phylogenetics—due wk. 3 ■ ***Quiz 2***			10	35	12
3	Jan 30–Feb 3	■ ***In-Class:*** Isolate fish proteins ■ ***Homework:*** Write intro.—due wk. 4 ■ ***Quiz 3***			10	15	12
4	Feb 6–10	■ ***In-Class:*** Electrophoresis ■ ***Homework:*** Write methods—due wk. 5 ■ ***Quiz 4***			10	10	12
5	Feb 13–17	■ ***In-Class:*** View gels ■ ***Homework:*** Results and discussion—due wk. 6 ■ ***Quiz 5***			10	20	12
6	Feb 20–24	■ ***In-Class:*** Database ■ ***Homework:*** Write fish report—due wk. 7 ■ ***Quiz 6***	■ ***In-Class:*** Intro to plants ■ ***Homework:*** Proposal—due wk. 7		20	25 50	12
7	Feb 27–Mar 3	■ ***Homework:*** Peer review	■ ***In-Class:*** Propose plant experiment ■ ***Quiz 7***		20	25	12
Mar 6–10		Spring Recess—No Labs					
8	Mar 13–17	■ ***Homework:*** Revise fish reports—due wk. 9	■ ***In-Class:*** Set up plant experiment ■ ***Homework:*** Work on introduction and methods—submission for TA feedback ■ ***Quiz 8***		10	125	12
9	Mar 20–24	■ ***In-Class:*** Fish Report Due	■ ***In-Class:*** Practice data collection/stats and graphing ■ ***Homework:*** Work on figures and results—submission for TA feedback ■ ***Quiz 9***		10		12
10	Mar 27–31		■ ***In-Class:*** Data collection/stats and graphing ■ ***Homework:*** Write plant reports—due wk. 11 ■ ***Quiz 10***		10	25	12
11	April 3–7		■ ***Homework:*** Peer review	■ ***In-Class:*** Introduction and research ■ ***Quiz 11***	10	25	12
12	April 10–14		■ ***Homework:*** Revise plant reports—due wk. 13	■ ***In-Class:*** Data collection on blackworms and *Daphnia sp.* ■ ***Homework:*** Comparative physiology questions and mini-presentation—due wk. 13	10	125 70	
13	April 17–21		■ ***Lab report due***	■ ***Lab presentations***		15	
14	April 24–28	■ ***Last week of classes***					
				Total Points	140	600	140

Appendix G: Plant Nutrient Summative Assignment Rubric. This rubric is used for both the rough draft and the final draft.

Biology 117 Plant Nutrient Report Rubric

Title Section	**_____/ 2 pts.**
_____/ 1 pt.	☐ Pertinent information (title, author's name, lab partner names, lab section, date, day, time, and TA's name) is present.
_____/ 1 pt.	☐ Title gives the reader a concise, but full description of the topic.
Introduction	**_____/ 25 pts.**
 _____/ 3 pts. _____/ 7 pts. _____/ 1 pts _____/ 2 pts.	☐ Introduction starts with accurate, relevant background information that helps the reader to build a picture of the topic to be discussed. Keep your audience in mind; write for your peers, a general audience of beginning college students. - *Plant nutrients:* What is an essential nutrient? What are micro-and macronutrients? Where do they come from? - *Deficiencies, general and your specific deficiency:* Why are they important? What happens if a plant lacks an essential nutrient? What functions could be affected or disrupted? What are typical characteristics of deficiencies? What causes deficiencies? How/why do you artificially create deficiencies in the lab? - *Model species information:* Why is *Brassica rapa* a good model? - *Techniques introduced:* Quantification of stomatal density. Photosynthetic pigment measurements using spectrophotometry. Growth measures. Other deficiency symptom measures.
_____/ 4 pts.	☐ Appropriate rationale is included; the reader will understand the scientific reasoning for doing the research and how it adds to the body of current research.
_____/ 5 pts.	☐ All information is derived from or supported by appropriate sources (primary literature, reliable secondary sources, NO websites). At least five sources are required for the full report. A minimum of three should be primary sources. - If any secondary sources are used, they are reliable (e.g. review articles, textbooks) - References indicate an extensive primary literature search was done. Helpful resources include Academic Search Complete or Ebscohost through WVU Libraries (www.libraries.wvu.edu) and Google Scholar.
_____/ 3 pts.	☐ Purpose or objective of research is clearly stated and is included at the end of the Introduction section. A properly written hypothesis is also acceptable.
Methods	**_____/ 18 pts.**
_____/ 1 pts.	☐ Written in complete sentences, not a bulleted list. Subheadings are included within the section. (E.g. "Experimental setup," "Measurement of photosynthetic pigments," etc.)
_____/ 2 pts.	☐ Written in past tense.
_____/ 1 pts.	☐ Not a list of instructions; avoids "First…Second…," or "Next…and then…," etc.
 _____/ 2 pts. _____/ 2 pts. _____/ 2 pts. _____/ 2 pts. _____/ 1 pt.	☐ Level of detail is appropriate; Includes relevant details, does not include unnecessary information. - Experimental setup: number of plants, treatments, preparation of solutions, watering regimes, etc. - Measurement of photosynthetic pigments - Stomatal density - Plant growth and biomass, any measurements repeated over time - Description of data analysis (means, standard error, t-tests, etc.)
_____/ 5 pts.	☐ Someone could reproduce the procedure after reading your methods section.
Results	**_____/ 10 pts.**
_____/ 2 pts.	☐ Section is written in complete sentences.
_____/ 6 pts.	☐ Descriptions of data/figures are relevant, accurate, and complete. All important data trends and findings are included.
_____/ 2 pts.	☐ Statistical p-values are reported. Significance/non-significance is indicated.

Figures & Tables	**_____/ 15 pts.**
	☐ Graphs of data are included
_____/ 2 pts.	- Graph types are appropriate (line graph for continuous data or bar graph non-continuous data)
_____/ 2 pts.	- Data points represent means
_____/ 2 pts.	- Standard error bars are correctly calculated and included on the figures
_____/ 2 pts.	- Axes have labels with units
_____/ 2 pts.	- Overall the graphs are neat and clear
_____/ 5 pts.	☐ All figures and tables have a description/legend and are placed above tables and below figures. The description/legend contains a title and brief description of what is shown.
Discussion	**_____/ 30 pts.**
_____/ 3 pts.	☐ The author indicates whether or not the objectives of the experiment were met and/or whether or not hypotheses were supported.
	☐ The class data is interpreted and discussed including:
_____/ 4 pts.	- Explain how your actual results compare with what was expected.
_____/ 4 pts.	- How do your results compare with data from the literature? Use existing information to put your results in context.
_____/ 4 pts.	- How can you explain any unexpected results? How might you test those possible explanations?
_____/ 8 pts.	☐ Future directions are discussed. Based on your results, what are the next questions you would logically want to ask next? You may include any limitations of the experiment and suggest how they might be avoided in future experiments.
_____/ 7 pts.	☐ All information is derived from or supported by appropriate sources (primary literature, reliable secondary sources, NO websites). At least five sources are required for the full report. A minimum of three should be primary sources. - If any secondary sources are used, they are reliable (e.g. review articles, textbooks) - References indicate an extensive primary literature search was done. Helpful resources include Academic Search Complete or Ebscohost through WVU Libraries (www.libraries.wvu.edu) and Google Scholar.
References	**_____/ 10 pts.**
_____/ 10 pts.	☐ Proper format is used to reference both in-text citations and in Literature Cited Section at the end of report. (See Chapter 5 in *A Short Guide to Writing About Biology* by Jan A. Pechenik for formats.)
Writing Style	**_____/ 15 pts.**
_____/ 3 pt.	☐ Grammar check and spelling is completed.
_____/ 3 pt.	☐ Sentences have proper subject/verb agreements as well as other important writing elements, such as transitions.
_____/ 3 pt.	☐ Subheadings are provided to guide the reader from one section of your report to another.
_____/ 3 pt.	☐ The report shows careful attention to the flow of ideas, both within and among paragraphs. It is organized in a logical fashion.
_____/ 3 pt.	☐ Overall, the writing is clear and the report is easy to understand.

Total _____/125 pts. For first full draft: Total _____ * 0.20 = _____/25 pts.

Appendix H: Codes associated with theme construction for Pilot Study. All codes appeared in multiple interviews. Codes were initially much broader but collapsed due to similarity and then converged to generate the themes.

Themes	**Codes Associated with Theme**
Students enter into the field literature and have to reconcile and restructure information.	Dissonance Knowledge Construction Schema Repair Superficial Learning No New Research Omnipotent in Science
Students gauge credibility through what they think is important	Credibility Variability Consistency Support Source
Students make meaning/understanding of their own research, which includes understanding research of others.	Incorporate Own Interpret Own Comprehend Own Incorporate other Interpret Other Comprehend Other
Students write for conventions and not for science literacy.	Convention Statistics Visual Representation Experimental Design Writing for Grade Writing Style Peer Review

Appendix I: Research Questions, Data Sources, Collection, and Analysis

Research Question 1	Data Sources	Data Collection	Analysis
How do students demonstrate science literacy at different points in the writing process as they work towards completing a manuscript-style writing assignment?	Stimulated Recall Interview (audio	1 Interview Per Participant (transcription)	Use inductive/deductive coding with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes.
	Final Paper	1 paper per participant	Use inductive/deductive coding with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes.
	Metacognitive Reflection (Rough Draft)	1 per participant 1st of two reflections→ Students will reflect on the writing of the rough draft	Use inductive/deductive with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes. **This may not show instances of it but it could be discussed**
	Metacognitive Reflection (Think Aloud)	1 per participant 2nd of two reflections→ Students will reflect on the reviewing process	Use inductive/deductive with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes. **This may not show instances of it but it could be discussed**
	Rough Draft of Paper	1 paper per participant	Use inductive/deductive coding with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes.
	Think-Aloud Interview	1 interview per pair of participants	Use inductive/deductive coding with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes.
Research Question 2	**Data Sources**	**Data Collection**	**Analysis**
How do course artifacts (drafts and rubric)	Rough Draft	1 Paper per Participant (Artifact)	Use inductive/deductive coding with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes.

related to this assignment demonstrate science literacy?	Final Paper	1 paper per participant	Use inductive/deductive coding with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes.
	Assignment Rubric	1 rubric per entire study.	Use inductive/deductive coding with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes. **This may not show instances of it but it could be discussed**
Research Question 3	**Data Sources**	**Data Collection**	**Analysis**
How do students talk about what it means to be scientifically literate	Stimulated Recall Interview (audio)	1 interview Per Participant (transcription)	Use inductive/deductive coding with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes.
	Pre-Interview	1 interview per participant	Use inductive/deductive coding with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes.
	Metacognitive Reflection (Rough Draft)	1 per participant 1st of two reflections→ Students will reflect on the writing of the rough draft	Use inductive/deductive coding with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes. **This may not show instances of it but it could be discussed**
	Metacognitive Reflection (Think Aloud)	1 per participant 2nd of two reflections→ Students will reflect on the reviewing process	Use inductive/deductive with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes. **This may not show instances of it but it could be discussed**
	Think-Aloud Interview	1 interview per pair of participants	Use inductive/deductive coding with the codes from the pilot study as a guide; condense and collapse across to build categories and then themes.