5-2017

Claim, Evidence, and Reasoning: Evaluation of the Use of Scientific Inquiry to Support Argumentative Writing in the Middle School Science Classroom

Gabriela Mastro
Dominican University of California

https://doi.org/10.33015/dominican.edu/2017.edu.09

Claim, Evidence, and Reasoning:

Evaluation of the Use of Scientific Inquiry to Support Argumentative Writing in the Middle School Science Classroom

Gabriela Mastro

Submitted in Partial Fulfillment of the Requirements for the Degree

Master of Science in Education

School of Education and Counseling Psychology

Dominican University of California

San Rafael, CA

May 2017

Signature Sheet

This thesis, written under the direction of the candidate's thesis advisor and approved by the Chair of the Master's program, has been presented to and accepted by the Faculty of Education in partial fulfillment of the requirements for the degree of Master of Science. The content and research methodologies presented in this work represent the work of the candidate alone.

Gabriela Mastro Candidate	May 1, 2017 Date
Madalienne F. Peters, Ed.D. Thesis Advisor Program Chair, Master of Science in Education	May 1, 2017 Date
Robin Gayle, Ph.D., MDIV, MFT Acting Dean School of Education and Counseling Psychology	April 24, 2017 Date

Acknowledgments

I would like to thank Madalienne Peters for all of her dedication to her students. Her forceful, yet positive and encouraging approach to this process was truly valuable to the completion of this project. Without her encouragement to “get the words on the paper,” I don’t know that I would have. I would also like to express my gratitude to Kate McDougall for equipping her students with the necessary tools to incorporate literacy into all subject areas. The skills I learned in her class were the inspiration for this project. I am truly thankful for all of the faculty at Dominican that I have worked with over the past three years – Rebecca Birch, Shadi Roshandel, Elizabeth Truesdell, and all others – for supporting and inspiring me throughout this journey.

I could not be more blessed to work with such wonderful colleagues, who are not only truly gifted teachers, but also amazing friends. Thank you for all of the support, encouragement, and fun. Our students are extremely lucky to have such innovative and caring teachers, and I am equally as lucky to be part of such a dynamic community of educators.

Most of all, I would like to thank my family, especially my parents, Lucina and George Mastro, for their forever, unconditional, and unquestioning love and support.

Table of Contents

Abstract

In light of the essential science and engineering practices identified by the Next Generation Science Standards (NGSS), this study focuses on the specific science and engineering practice, "engage in argument from evidence," and how classroom practices can serve to strengthen this skill (National Research Council, 2012, p. 71). The NGSS focus on inquiry necessitates students’ use of argument, particularly in writing, to communicate their knowledge and scientific findings and to develop an understanding of scientific practice. The purpose of this teacher action research study is to evaluate the influence of inquiry-based argumentative writing exercises, based on the Argument Driven Inquiry (ADI) model, in a middle school science classroom (Sampson, Grooms, and Walker, 2011). The ADI model, while extensive and complex, shows promise in building both argumentative writing skills and science content knowledge. The results of this study demonstrated that modified iterations of this model should include data sets that are personally meaningful to students, writing tasks scaffolded to areas of student need, and clear communication of feedback, from both peers and teachers, focused on all three areas of scientific arguments: claim, evidence, and reasoning. Information gained from this study will benefit science educators by yielding information about how scientific argumentative writing can be most effectively implemented into the middle school classroom to yield the maximum benefit for literacy in the science curriculum.

Keywords: science, middle school, science and engineering practices, argumentative writing, Next Generation Science Standards

Chapter 1 Scientific Argumentative Writing

Since California's adoption of the Common Core State Standards (CCSS) in August 2010 and the Next Generation Science Standards (NGSS) in September 2013, the face of science education has been changing drastically. These two sets of standards arose from concerns about the U.S. position in the global economy and the preparedness of its students to eventually be able to participate in an increasingly science- and technology-driven society. As such, the NGSS and CCSS place an increased emphasis on college and career readiness, as well as competence in science literacy and science and engineering practices.

Science education prior to NGSS, overall, consisted of "long lists of detailed and disconnected facts," leaving students with "just fragments of knowledge and little sense of the creative achievements of science, its inherent logic and consistency, and its universality" (NRC, 2012, p. 10). In response, the NGSS were intentionally developed in three dimensions: scientific and engineering practices, cross-cutting concepts that are applicable across scientific disciplines, and disciplinary core ideas. In comparison to several previous sets of state standards, the NGSS have led to an increased emphasis on scientific inquiry. Bowman and Govett (2015) stated that, as rapid progress is being made in all fields of science, the NGSS was created to be dynamic, emphasizing core ideas and skills, such as "technical reading, interpretation, critical thinking, and analysis," rather than mere simple facts (p. 55). In order for students to develop those skills, they need to continuously engage in scientific practice, and the NGSS encourage students' generation of models and evidence-based explanations as tools to meet this end.

Furthermore, the NGSS were specifically aligned with the CCSS in both math and English/language arts (ELA). This alignment was developed to address an increasing need for students to be able to communicate scientifically. Since much of scientific discourse consists of creating and defending evidence-based claims, the ability to "engage in argument with evidence" was included in the NGSS as a science and engineering practice, which is supported by several ELA anchors in the CCSS.

One challenge of incorporating the CCSS ELA standards with NGSS is that skills that students learn in ELA classes do not necessarily transfer to scientific writing. I observed this during my second semester as a middle-school science teacher. Initially, it seemed a result of a lack of effort on the students' part – that they did not expect to engage in formal written assignments in science classes, and that the writing standards from their English classes did not apply. In accordance with a renewed district focus on incorporating literacy into all subject areas, I made it a personal goal to make sure that students in my science classes engaged in frequent writing assignments.

One common technique that students utilized in their ELA classes was "Step-Up-to-Writing," (*Step Up to Writing*, n.d.) a technique for writing paragraphs that enabled students to construct high-level paragraphs according to a formula, where facts and details were used to support a main topic. In order to support students' ability to "argue from evidence," the terminology was replaced. Instead of writing a topic sentence, students would make a "claim," instead of a "fact," "evidence," and instead of "details," "reasoning." I presumed that, by simply replacing the terminology to fit my purpose, students would be able to seamlessly transfer the skills from their English classes to their science class.

As a first-year teacher, I conducted a small-scale inquiry, as part of a teacher induction program, to evaluate the effectiveness of the "claim, evidence, reasoning" (CER) model. In order to collect quantitative data, students were administered a pre- and post-assessment aimed at evaluating students' ability to incorporate claims, evidence, and reasoning into a "Step Up to

Writing" paragraph (*Step Up to Writing*, n.d.). Surprisingly, the students, overall, actually performed worse on the post-assessment. Even though the "Step Up" paragraphs were adapted as a model for scientific communication, there was a clear disconnect between students' ability to communicate in writing in their language arts classes and their ability to do so in their science classes. Scientific writing and writing in other subject areas are so inherently different, that it seems as if the students need to be explicitly taught how to engage in scientific argumentative writing, without necessarily relying on techniques taught in ELA classes.

Statement of Problem

Students are taught how to write argumentatively in language arts contexts, but those skills do not automatically transfer to science. One would assume that mastery of writing fundamentals would lead to success in writing tasks in all subject areas, but not all teachers and not all subject areas require students to engage in frequent writing exercises. Kiuhara, Graham, and Hawken (2009) surveyed high school science teachers, finding that there was a lower importance on the value of writing in science classes than in other subject areas, along with a lower overall writing frequency. Due to a general lack of support for writing in the science curriculum, even when cross-curricular scaffolds are used, students may struggle with writing tasks that are science-specific, including tasks that require students to support scientific claims by "arguing from evidence." It is clear that literacy skills taught in language arts classes are just one component of a student's capacity to write scientifically, which implies that science teachers need to draw on different techniques to explicitly teach literacy in the science curriculum (Norris & Phillips, 2003).

Purpose Statement

The purpose of this study is to evaluate the effectiveness of inquiry-based argumentative writing exercises in the middle school science classroom on students' ability to "engage in argument from evidence" (National Research Council, 2012, p. 71). The aim of this research is to yield further information on how argumentative writing can be scaffolded within the science classroom, and to bring to light aspects of scientific argumentative writing that students struggle with. In addition, this research will also provide some information on how middle school science teachers can effectively collaborate with other content area teachers to support the development of students' argumentative writing skills in all subject areas.

Research Question

The primary question in this study is to determine how inquiry-based argumentative writing exercises can be effectively used in the middle school science classroom to foster students' ability to "engage in argument from evidence" (NRC, 2012, p. 71). By collecting data to answer this question, more questions arise. Secondary research questions include the following: What are some common deficiencies in scientific argumentative writing pieces? How can teachers scaffold writing assignments to better combat these common deficiencies? How can the information gained from examining these writing pieces inform further argumentative writing instruction in the science curriculum and beyond?

The term "engage in argument from evidence" is derived from the Science and Engineering Practices (SEP) of the NGSS. The SEP were drafted under the assumption that it was necessary for students to "engage in the practices and not merely learn about them secondhand," in order to fully comprehend the nature of scientific practice (NRC, 2012, p. 30).

In accordance with the inquiry emphasis in the NGSS, the SEP are specific practices that help to clarify the process of scientific inquiry (NRC, 2012).

"Engaging in argument from evidence" involves engaging in a process of reasoning "that requires a scientist to make a justified claim about the world" (NRC, 2012, p. 71). The ability to identify weaknesses and limitations of a claim is just as essential, in order for students to critically evaluate their own work and that of other students and scientists. In this study, "engaging in argument from evidence" will involve the use of claims, evidence, and reasoning to construct arguments. A "claim" is an overarching answer to a scientific question that is the focus of a lab experiment and the associated lab report. "Evidence" is the data collected in order to answer this scientific question. "Reasoning" is the analysis intended to explain the connection between the evidence and the claim.

For the purposes of this research, "scientific literacy" is considered too broad of a term to describe a student's ability to read and write scientifically. Fives, et al. (2014) define "scientific literacy" as "knowledge of the nature of the field and its processes so that one can engage (in whatever form that takes for the individual) with science pragmatically and meaningfully in daily life" (Fives, et al., 2014, p. 551). This research focuses not on scientific literacy in a broader sense, but on the ability to communicate about scientific concepts through writing. As this study will be focused on developing this skill in middle school students, this skill will be referred to as "literacy in the science curriculum."

This research will define "argumentative writing" as any piece of writing where students make a clear claim, support this claim with evidence from external sources or labs, and analyze and interpret this evidence to defend their claim.

"Scientific inquiry" is "an active learning process in which students answer research questions through data analysis" (Bell, Smetana, & Binns, 2005, p. 31). These questions and data can either be created and collected independently by the students, themselves, or can be provided, as long as students are engaging in their own analyses and drawing their own conclusions.

Theoretical Rationale

The research documented in this paper is based on the SEPs within the NGSS, specifically, engaging in argument from evidence. The National Research Council (2012) contends that "learning to argue scientifically offers students not only an opportunity to use their scientific knowledge in justifying an explanation and in identifying the weaknesses in others' arguments but also to build their own knowledge and understanding" (p. 73). This practice is indicative of an increased emphasis on communication and collaboration within NGSS and the Common Core State Standards. Therefore, the theoretical basis of social interaction and argumentation in the classroom can serve as a foundation for this research question.

According to Vygotsky **(**1978**)**, learning and its social context are inextricably linked. He theorized that "all the higher functions emerge as actual relationships between individuals," and that learning was the process of integrating into a "knowledge community" (Vygotsky, 1978, p. 57)**.** Vygotsky's theory of social constructivism emphasizes the importance of the "more knowledgeable other" (MKO), which is someone with more knowledge and experience than the learner. Communication with this MKO can help solidify understanding of a particular concept, which leads to learning. This concept is the theoretical foundation of the increased emphasis on collaboration and communication in the classroom. The goal is for students to discuss content with peers or teachers. In the case of science classrooms, this happens whenever students are asked to provide evidence or communicate their findings. Therefore, when the NGSS specify that students are expected to use evidence to construct arguments within their science classrooms, these arguments, as means of communication between peers or with the teacher, can be used as a tool to build overall scientific inquiry and literacy skills.

The adoption of the NGSS and the CCSS have led to a shift to collaborative environments in not only science classrooms, but all classrooms. The adoption of these standards have led to an increased demand on science teachers to teach literacy skills within their content areas (Bowman & Govett, 2015). Collaboration can be used as a method to teach these literacy skills. One of the purposes of teaching literacy in the science classroom is to enable students to actively engage, in reading and writing, with the scientific community, and in order to do this, students need to be able to operate within their zone of proximal development. By engaging in collaborative literacy practices, with the support and guidance of their teacher and more experienced peers, students are more likely to develop the scientific literacy skills they will need to engage with science in real life.

Assumptions

Although a background in the fundamentals of literacy can support scientific literacy skills, the ability to read and write does not, alone, indicate a student's ability to communicate in a scientific manner by "engaging in argument through evidence." In order to successfully engage in these practices, students need to be explicitly taught the conventions and discourse of scientific writing.

Each content area has its own set of conventions and rules of discourse, which are taught by the content-area teacher. Although teachers may be familiar with the conventions of multiple subject areas, it is not the responsibility of a content-area teacher to teach the discourse of a different subject area. It can be assumed that it is the science teacher's responsibility to teach the rules of scientific discourse, and these rules will not be covered in any other content area. Therefore, it is critical that science teachers include literacy in their content area so that their students will have a solid foundation in scientific communication.

Background and Need

The adoption of NGSS and CCSS have placed an additional demand upon science teachers to integrate writing into the curriculum. In recent years, a national survey indicated that, overall, science teachers did not require their students to write, and provided very little explicit instruction on writing. They also viewed writing as less important compared to the perspective of social studies and language arts teachers (Kiuhara, et al., 2009). This study hypothesized that science teachers may not view teaching writing as their responsibility, or that they believe that students already possess the necessary writing skills. Since the adoption of NGSS and CCSS, improvements may have occurred, but nonetheless, since this change in policy is recent, many science teachers are in the process of developing curriculum and teaching strategies to support writing practice in their classrooms to meet these new standards.

Sampson, et al. (2013) and Grooms, et al. (2015) examined one method of incorporating argumentative writing into the science curriculum, called “Argument-Driven Inquiry.” This method is comprised of a series of steps. First of all, the teacher identifies the task, the students design a method for data collection and analysis, and based on that data, develop a tentative argument. From there, students engage in an “argumentation session” where they critique each other’s scientific arguments, and the teacher uses those arguments to facilitate a reflective discussion. (Grooms, et al. 2015) Students write a report of their findings, which then undergoes peer review before final submission. These two studies describe similar results, where students participating in ADI instruction make significant gains in both their science content knowledge and argumentative writing skills.

However, one major limitation of this model of instruction is the fact that the process is extensive. Realistically, it would be very difficult for a teacher to implement this model with fidelity for every single lab or content standard. Despite this, the ADI model contains several useful strategies that can be implemented to support argumentative writing in the science curriculum. One need that both Sampson et al. (2013) and Grooms, et al. (2015) identified was to determine which components of the ADI model are "non-negotiable." This research will hopefully support this need by, modifying this model of instruction into a new iteration that can be regularly implemented into the middle school science curriculum more feasibly, identifying data trends that indicate areas where students need more support, and providing suggestions for future modifications to this model of instruction.

Summary

As implementation of NGSS and CCSS begins to take its full effect, science teachers are trying to determine how to best implement the standards and essential practices into their curriculum. These standards are still in the beginning stages of implementation, and although they have been articulated, not much guidance has been given for teachers or administrators (Bowman & Govett, 2015). Until the adoption of NGSS and CCSS, science content-area literacy instruction has been lacking, overall (Kiuhara, et al., 2009). Therefore, in addition to the need for research-based suggestions and tools for integrating these standards within the science curriculum, there is also a need for guidance in incorporating literacy in the science content area. In particular, this study aims to evaluate the use of argumentative writing exercises on students' ability to "engage in argument from evidence." Since the world of science teaching is going through such major changes, and is in need of guidance for how to adapt curriculum to these changes, this research will inform future science instruction by providing research-based suggestions and practices for building students' scientific argumentative writing skills.

Chapter 2 Review of the Literature

Introduction

Scientific literacy is a broad topic with no commonly accepted working definition of the term. As such, this study addressed one aspect of scientific literacy – the ability to communicate in a scientific manner through writing. Specifically, students practiced “engaging in argument through evidence,” which was measured through samples of argumentative writing (NRC, 2012). In order to evaluate the impact of inquiry-based argumentative writing, some background is needed about how literacy and argumentative writing fit into the science curriculum. This review of the literature examined the role of the historical context of scientific literacy instruction on the development of the NGSS and CCSS, which, in turn, influenced the future direction of teaching literacy within the science classroom.

A review of the literature revealed the following themes: 1) The NGSS and the CCSS have drastically changed the way that inquiry and collaboration are implemented into the science curriculum, which, in turn, have an impact on the possibilities for teaching writing within the science curriculum. 2) Inquiry, as well as communication of its process and findings, can be used as a method for creating meaning of science concepts. 3) Inquiry practices and writing can combine, as students utilize scientific processes and evidence to develop and defend arguments. 4) Argument Driven Inquiry (ADI) can be used as a tool to deliver instruction on inquiry-based argumentative writing. 5) Teachers’ abilities to implement these practices into the science curriculum can be limited by their own self-efficacy, a perception that fundamental literacy instruction has no place in the science curriculum, inadequate professional development, lack of funding, and numerous other issues.

Historical Context

On October 4, 1957, Soviet Russia launched the satellite *Sputnik*, indicating that the U.S. may have fallen behind in scientific research, technology, and engineering. This huge blow to national pride is seen as the catalyst for the development of modern science education. Following this event, policymakers recognized a need for educational reform, particularly in science and math, if the U.S. were to continue to be a competitive global force. Attention turned toward improving the quality of secondary science teachers, as well as the national science curriculum, as a whole. The hope was that in making science a rich, interesting subject area that encouraged the pursuit of further science education, the U.S. would emerge victorious in the “space race” with Soviet Russia.

As the Cold War continued, the fear of the U.S.’s loss of global dominance emerged with the publication of *A Nation at Risk: The Imperative for Educational Reform*. In this report, the National Commission on Excellence in Education put forth that the educational system of the U.S. was in such disrepair that the U.S. would continue to fall behind other nations in the areas of industry, science, technology, and commerce (1983). This report spurred a parade of science education reform initiatives that would occur over the next three decades.

In 1996, the National Research Council developed the National Science Education Standards. Their goal was to “spell out a vision of science education that will make science literacy for all a reality in the 21st century” (NRC, 1996, p. ix). These standards outlined what students needed to know, understand, and be able to do in order to achieve this goal, calling for a greater emphasis on inquiry-based science education.

Although the National Science Education Standards were a nationwide effort to improve science education, by the early 2000s, each state had its own set of standards and its own expectations for proficiency. Beginning in 2009, the Common Core State Standards (CCSS) began development as an effort to standardize education across the U.S., which would give the states more educational common ground. As of 2015, forty-two states, as well as several territories had adopted the CCSS for English/Language Arts (ELA) and mathematics. The CCSS emphasized several key shifts in ELA. Specifically, the CCSS highlighted the regular use of complex texts and academic language, communication with the use of evidence from literary and informational texts, and the use of nonfiction text to build knowledge.

In 2009, the Carnegie Foundation released a report entitled *The Opportunity Equation: Transforming Mathematics and Science Education for Citizenship and the Global Economy.* With echoes of *A Nation at Risk*, this report bemoaned the lagging achievements of students in science and mathematics and the U.S.'s reduced global economic power (*Opportunity Equation*, 2009). In response, the development of the NGSS began in 2011. The aim of these standards was to prepare students for careers in a society increasingly driven by science and technology and to increase the overall scientific and technological literacy of U.S. citizens to enable meaningful participation in this society (*Opportunity Equation*, 2009). The NGSS were released for adoption by states in May 2013, and was adopted in California in September 2013. California is currently in the implementation phase of NGSS, and science teachers are currently working to align curriculum, instruction, and assessments to the standards.

The NGSS were written specifically to align with the CCSS. In the area of literacy, the NGSS development team worked with the CCSS literacy team to "identify key literacy connections to the specific content demands outlined in the NGSS" (NGSS Lead States, p. 159). The final version of the NGSS drew specific connections to the CCSS for ELA, ensuring that the two sets of standards would be aligned. Appendix M of the NGSS release (2013) examined each SEP in the NGSS, identifying the aligned CCSS literacy anchor standards. The rationale was that "writing and presenting information orally are key means for students to assert and defend claims in science, demonstrate what they know about a concept, and convey what they have experienced, imagined, thought, and learned" (NGSS Lead States, p. 159). This deliberate alignment of NGSS with the CCSS ELA standards emphasize that the two sets of standards are intended to work together to build students' abilities to read and write scientifically, as they engage in inquiry-based scientific practice. As such, this literature review examined how the practice of scientific inquiry is connected to literacy within the science curriculum, and how that connects with an argument-based classroom culture.

The Next-Generation Science Standards and Inquiry-Based Learning

As the NGSS have been adopted in several states, teachers are contemplating how to best address them in their curricula. A study by Bowman and Govett (2015) compared the life science standards in the NGSS to the corresponding standards of the Tennessee Curriculum Standards for Science Education (TNCSSE). This comparison allowed them to conclude that as the field of science is rapidly changing and evolving, often too quickly for textbooks to reflect these new understandings, there is a clear need for students to develop a broad understanding of key science topics, in order to expand on any new science information that may come to light. The NGSS place a new focus on certain learning skills, "such as technical reading, interpretation, critical thinking, and analysis rather than factual learning" (Bowman & Govett, 2015, p. 55), in order to allow students to achieve content learning goals. The NGSS incorporate inquiry as part of the content standards, rather than communicating this focus as a set of separate standards. Bowman and Govett observed that, “simply teaching the standards as written requires an embedded inquiry that surpasses the TNCSSE standards” (p. 59). In light of this, an understanding of what, exactly, entails “inquiry” needs to be established.

When teaching through an inquiry lens, teachers make pedagogical decisions “to promote scientific practices such as asking testable questions, creating and carrying out investigations, analyzing and interpreting data, drawing warranted conclusions, and constructing explanations that promote a deep conceptual understanding of fundamental science ideas” (Wilcox, Kruse, & Clough, 2015, p. 62). The researchers (2015) offered several insights for how inquiry can be implemented successfully in a science classroom. Inquiry can range from guided activities to more open approaches, depending on the amount of student support needed. Inquiry-based activities can be useful for differentiating curriculum due to the amount of concrete engagement and teacher interaction that they may require. While inquiry-based activities can consist of hands-on experiences, the most important thing is that students are making meaning of whatever activity they are engaging in, through decision-making, exploring their own thinking, and engaging in abstract thinking. Although an inquiry-based approach has been recommended for science education for many years, Wilcox, Kruse, and Clough (2015) claim that inquiry is not yet a common aspect of science teaching. They hypothesize that there is widespread misunderstanding of what it actually entails to facilitate inquiry-based learning.

Bell, Smetana, and Binns (2005) tried to clarify the meaning of inquiry learning. According to these authors, the following two criteria must be met for an activity to be truly inquiry-based:

a) Students are answering a research question through data analysis.

b) Students must be involved in analyzing relevant data. These data do not necessarily need to be collected by the students, themselves, but they need to be actively involved in interpreting this data and drawing conclusions from it.

Bell, Smetana, and Binns (2005) also define four "levels" of inquiry for teachers to use as guidelines to adjust an inquiry-based lesson to the readiness level of their students.

1. In "Level 1" activities, sometimes referred to as "confirmation activities," students are provided with the question and procedure, and the expected results are known in advance.

2. "Level 2," or "structured inquiry" activities provide students with the question and the procedure, but not the expected results. According to Bell, Smetana, and Binns (2005), the difference between Level 1 and Level 2 can be a matter of presenting the activity before or after the target concept is taught.

3. "Level 3," or "guided inquiry" begins with a teacher-presented question, but leaves the methods and solutions up to students, which may promote engagement and ownership.

4. "Level 4," or "open inquiries" allow students to design methods to investigate a topic-related question of their choosing. Successful Level 4 inquiries require students to have experience with inquiry at Level 1-3.

In Irish secondary schools, students undertake Junior Certificate programs, in which they participate in both mandatory and optional coursework in order to earn these certificates. Science, an optional subject that is studied by 95% of students, follows two parts: Coursework A or Coursework B (Kennedy, 2014, p. 286). Coursework A follows a sequence of thirty experiments, mandated by the Irish government. In the third year of this sequence, Coursework B requires students to complete two investigations, of the "Level 4" variety proposed by Bell, Smetana, and Binns (2005). However, when surveyed about these methods, 68.7% of science teachers "disagreed" or "strongly disagreed with the statement, "Coursework B is an accurate indicator of students' ability to carry out science investigations" (Kennedy, 2014, p. 295). Teachers reported that students' scores on Coursework B were based on the final presentation of material, not the skills learned while carrying out the investigations, which may also be influenced by peers, parents, teachers, and others who may offer assistance. A student's inquiry skills may be difficult to assess. Considering this, and the fact that inquiry-based science education can be difficult to implement, Kennedy (2014) does not recommend this teaching method as the sole means through which science education is delivered. Referring to studies that highlight the effectiveness of direct instruction on student achievement, Kennedy (2014) suggests that inquiry-based science instruction be balanced with direct instruction to maximize the student benefits.

Kennedy (2014) touches on the fact that several hurdles exist to the successful implementation of inquiry-based science education, on which Ramnarain (2016) further elaborates. Ramnarain's (2016) study focused on teachers at a township school in South Africa, examining the implementation of inquiry-based learning and the various influential factors. Teachers completed a questionnaire and were interviewed. Results demonstrated that the teachers had an overall lack of perceived self-efficacy and desired further professional development to increase their repertoire of inquiry teaching strategies. Furthermore, teachers indicated that their school did not have adequate resources to engage in this type of teaching. The teachers also asserted that they did not have enough time to plan inquiry-based instruction and that the school did not recognize its importance in the curriculum. However, despite these other findings, teachers maintained a positive attitude about inquiry teaching. Limitations of this study included the fact that only one school was examined and that classroom observations were not conducted. Overall, Ramnarain (2016) concluded that the practice of inquiry teaching is highly context-dependent, and the results can be used to inform guidelines for professional development for teachers who use these methods.

As Ramnarain (2016) and Kennedy (2014) pointed out, there are several obstacles to implementing inquiry-based instruction as a regular teaching practice, and some of the benefits to student content knowledge are unclear. However, Otfinowsky and Silva-Opps (2015) conducted a study on undergraduate biology students that highlighted the effect that inquiry-based instruction can have on the development of scientific literacy. Undergraduates enrolled in Vertebrate Zoology course at the University of Prince Edward Island, Canada, participated in a semester-long inquiry-based learning project. This project required students to create their own research questions and methods to present and discuss topics in vertebrate zoology. Students participating in this process engaged in regular reflective writing exercises to supplement their project work, and ultimately demonstrated more understanding of the role of scientific writing and communication. Despite all of the obstacles and hesitations that teachers may face in implementing inquiry-based education in science, student engagement in inquiry projects demonstrates the potential to build overall competence and confidence in scientific writing.

Implementing Literacy within the Science Curriculum

The concept of “scientific literacy” is broad, and consists of much more than the ability to read scientific literature and write in a way that conforms to the norms of the field. According to Fives, et al. (2014), scientific literacy is “knowledge of the nature of the field and its processes so that one can engage (in whatever form that takes for the individual) with science pragmatically and meaningfully in daily life” (Fives, et al., 2014, p. 551). In an attempt to create a working assessment of scientific literacy skills in middle school students, Fives, et al. (2014) defined six essential components of scientific literacy: 1) “The role of science,” which encompasses the understanding of scientific questions, methods, and evidence. 2) “Scientific thinking and doing,” which involves the actual observational and analytical processes needed to engage in science. 3) “Science and society,” where students can identify scientific issues in society and the role of science in decision-making. 4) “Science media literacy,” which is the ability to critique the media’s representation of scientific findings and issues. 5) “Mathematics in science,” where mathematical concepts can be used to engage in scientific processes. 6) “Science motivation and beliefs,” which is the ability to draw upon scientific knowledge and skills in one’s daily life.

Since scientific literacy encompasses a variety of scientific skills and attitudes, it is difficult to assess a student’s scientific literacy, as a whole. What can be done, however, is to consider scientific literacy in terms of these smaller components, which can be assessed separately and targeted separately for further instruction. The focus of this research is to measure student ability to write scientifically, which encompasses a small component of scientific literacy. However, this study highlights the importance of not only teaching scientific concepts, but also giving students opportunities to develop beliefs and values about science in the world.

A study by Tomas and Ritchie (2015) demonstrated how incorporating writing into the science curriculum can be used as a tool for making meaning of science concepts. Tomas and Ritchie (2015) examined the use of "BioStories," a writing-to-learn strategy, where students created stories about biosecurity. This task was aimed at developing students' scientific inquiry skills, to evaluate to what extent this program developed students' scientific literacy – both in terms of scientific content knowledge and in the ability to understand how science relates to human affairs. Analysis of the writing tasks revealed an improvement in scientific literacy, which indicated that participation in the writing tasks yielded a positive impact on learning, with 19 of 24 students in the case study demonstrating deep levels of conceptual understanding. This study indicates that writing itself can assist students with acquisition of content knowledge. Writing does not necessarily need to be kept separate from scientific content knowledge, but can be used as a tool to build this knowledge.

Hand, Hohenshell, and Prain (2007) conducted a similar study on high school students. Students studying cells were asked to write a textbook explanation for seventh-graders, using a "Science Writing Heuristic" (SRH). The SRH provided scaffolding questions that incorporated inquiry and argumentation processes to assist students in formulating their explanations through evidence, constructing arguments from additional research sources, and reflecting on their ideas. In contrast to another group of students, who wrote a newspaper article about molecular biology concepts without using the SRH, students who used the SRH performed better on science content tests. Since there was such a clear contrast between the students who received scaffolding from the SRH and those that did not, this raises a question of how writing can be supported within the science curriculum so that it can be used as a tool for acquiring content understanding.

Strategies

Norris and Phillips (2003) contest that literacy in its fundamental sense, "reading and writing when the content is science" (p. 224), is essential for scientific literacy. In contrast, scientific literacy is often referred to in the derived sense, "being knowledgeable, learned, and educated in science" (p. 224). The authors posit that just because a student is able to read the words, this does not give the reader the ability to comprehend and follow arguments, and thus, to engage in scientific inquiry. For educational purposes, teachers need to focus on both the content and the different interpretations of a text. Science students must both be familiar with the science content within a text and be able to read those texts from a theoretical perspective. Norris and Phillips (2003) emphasize the necessity of making sure that all students have access to the content being addressed within a science text by ensuring that students have the fundamental skills to see both the content on the surface and the implications within a text. Teachers cannot assume that students can have the literacy skills to effectively analyze texts and construct arguments. These skills need to be explicitly taught.

In order to accomplish this, Farris, Werderich, and Haling (2016) supply several suggestions. They recommend incorporating literature into science content instruction, due to the inherent connection between reading and writing. In addition, visuals, such as videos, increase relevance to the topic at hand and to encourage students to share this information through writing.

Finally, the author suggests that teachers provide note-taking scaffolds along with open-ended questions for students to respond to as they read and take notes. These suggestions, where students are provided with plenty of scientific resources in a variety of formats, are meant to connect the CCSS with the NGSS to not only enhance students' understanding of science, but to encourage them to communicate that information with others.

The qualitative results from the study by Hand, Hohenshell, and Prain (2007) demonstrated that when students were able to communicate their scientific knowledge by re-representing it for a different audience, this process allowed them the opportunity to clarify their own topic knowledge further. In addition, students reported that when they engaged in revision processes, they were able to clarify their own understanding. The use of the Science Writing Heuristic (SWH), and the fact that students who used it made more significant gains in content understanding than students who did not, demonstrated that students benefitted from the scaffolding that the SWH provided. In addition, students benefitted from communicating information with others, and they also benefitted from opportunities to revise their own work.

Towndrow, Tan, and Venthan (2008) followed a similar line of thought. Their argument maintained that science content learning lies within reflecting on experiences, and reflecting on how experiences connect to new situations. Therefore, they argue that reflection can promote scientific inquiry and a more robust understanding of content material. The use of science reflective journals was taught to a class of 7^{th} grade girls in Singapore, and entries that were initially factual and superficial progressed into more multi-faceted, inquiring pieces of writing. The journals helped students view science learning as an ongoing process. Towndrow, Tan, and Venthan (2008) argued that, if students have opportunities to engage in continuous reflection on what they are learning, they will be more adept at developing questions and thinking beyond the surface level. Therefore, in order to encourage continuous, deep thought, the teacher needs to allow for continuous reflection on classroom material.

Wright, et al. (2016) recognized a growing importance of incorporating literacy practices within the science curriculum, and examined the body of research on the topic, thus far, in order to determine future directions. This study examined articles published in the *Journal of Adolescent and Adult Literacy* that were related to scientific literacy, in order to determine which literacy theories are used to recommend instructional strategies, and to compare the articles in this specific journal with those published in science education journals. 63% of articles focused on vocabulary development, which indicates the strong push to focus on vocabulary and background knowledge, but these approaches do not truly engage students in building their overall literacy skills within the science content area. This indicates a need for researchers to investigate more practices supporting literacy in science, as well as other content areas. The CCSS and NGSS make strong recommendations for incorporating literacy into science, but provide little direction for how to do so, and this may be because a clear path does not exist. Therefore, research is needed to elucidate some practices that educators can use to implement strategies into their classroom that specifically support literacy in the content areas.

Implementing Argument within the Classroom Culture

Through a review of the literature, Cavagnetto (2010) concludes that argument within the science classroom is essential for students to transfer an understanding of scientific practice. Through argument, a student's overall scientific literacy can be supported as this understanding of scientific practice and norms merges with content knowledge. In practice, however, the practice of argument requires students to be able to construct an argument while utilizing appropriate evidence and science processes. At a more fundamental level, the process of argumentation builds overall literacy in the science content area as it develops skills such as metacognition and critical reasoning, and as students are immersed in the overall culture of science. Science cannot be possible without communication, both in writing and discussion. As a means of building these communication skills and familiarizing students with scientific practices, argument-based communication may serve as a useful part of the culture in science classrooms.

More specifically, Erduran and Jimenez-Aleixandre (2007, p. 5) proposed five research-based potential benefits of implementing argument into the science classroom: 1) Supporting cognitive and metacognitive processes and making those processes public through communication. 2) Allowing students to build competence in communication and critical thinking. 3) Empowering students to talk and write about science, and thus, build scientific literacy. 4) Immersing students in the scientific culture. 5) Supporting the development of reasoning skills.

Jimenez-Aleixandre and Rodriguez (2000) proposed that argumentation is a natural process that students engage in while collaborating with other students. They drew a distinction between “doing school” and “doing science,” and their research goal was to move science education away from “doing school” to “doing science.” The difference is that “doing science” involves engaging in scientific dialogue or argumentation, because scientific reasoning “involves making arguments to defend choices” (Jimenez-Aleixandre and Rodriguez, 2000, p. 759). Jimenez-Aleixandre and Rodriguez aimed to identify instances of “doing science” in the classroom, which argumentative operations were used in this process, and students’ use of epistemic operations related to knowledge construction. One class of Spanish high school students were observed and videotaped to identify instances of argumentation. The researchers noted that “doing science” is related to the learning environment, and that in working collaboratively, students engage in natural argumentation. One goal of science education is to develop learners’ “capacities to understand how we have come to know and why we believe what we know” (Jimenez-Aleixandre and Rodriguez, 2000, p. 758), and in doing so, they need to be able to communicate their cognitive and metacognitive processes behind those understandings. Since argumentation naturally occurs when students work in groups, this natural collaboration can be utilized to build a classroom culture centered on argumentation, which can be harnessed through writing.

Kelly and Bazerman (2003) examined high-scoring argumentative essays in an undergraduate oceanography class, with the aim of identifying “what constitutes successful performance” (Kelly and Bazerman, 2003, p. 37). They considered the student’s rhetorical moves, the level of generality of claim, and the coherence of arguments. Successful arguments showed a hierarchical structure, multiple cohesive lengths, sentences at the boundaries of sections and subsections that served as links with the other sections, and often-repeated terms that build up cohesion and saliency throughout the paper. This analysis provides science teachers with a model of what high-quality arguments should look like, and allows for reflection and choice-making. Kelly and Bazerman (2003) recommend explicit instruction on scientific discourse, which focuses on students becoming adept with making claims, linking them coherently, and tying those claims to specific data and evidence. Furthermore, they suggest that teachers make the structures of an argument visible and explicit.

Not only is argumentation and communication a goal of science classrooms, but also the NGSS and CCSS have recommended that science teachers integrate literacy into their subject area, and to build on ELA teachers' practice. Like in ELA, students are expected to critique and evaluate evidence to build arguments to support claims. The research by Kelly and Bazerman (2003) provides specific elements of what a "successful" argumentative paper looks like, as well as guidance on how to help students achieve that. These results and discussion can be used to formulate learning experiences that address argumentative writing conventions. With a newfound importance on scientific discourse in the classroom, teachers need to develop strategies to support English Language Learners (ELLs), along with struggling students and the class as a whole, with expressing themselves either in English or in their native language.

González-Howard, McNeill, and Ruttan (2015) described actual lessons from a sheltered English immersion classroom to demonstrate how teachers can help ELLs "engage in argument through evidence." Three strategies were highlighted as follows: "Discussing the meaning of the word or phrase related to argumentation," "Doing a think-aloud to model appropriate language to use during a task," and "Simplifying a complex claim by identifying key concepts in it." These strategies need not only apply to English learner students, but can be used to support all students in general education science classrooms to achieve this specific SEP.

Cheuk (2016) identifies four mechanisms for argumentation in the classroom: content knowledge, facility with the components of an argument, scaffolds, and group-worthy tasks. All of these components need to be considered in designing whole-class instruction, as well as instruction for ELL students, so that students can bring discourse into the classroom through their personal experiences, and feel supported while doing so. In addition, teachers need to consider classroom climate and culture, as well as how collaboration is structured. Cheuk (2016) describes several areas for future research, including an understanding of the "pedagogical content knowledge that teachers need to support this type of learning in our science classrooms" and the design of "instructional tasks that facilitate communicative opportunities that foster generative knowledge among ELLs and mainstream students who engage in argumentation in K-12s science classrooms. (Cheuk, 2006, p. 105) What might be helpful for these future directions, especially in middle school science classrooms, is to identify models of instruction that support this practice, and to evaluate the implementation of these models. With this, a better understanding of argumentative discourse within the science classroom can be gained, and future directions of research and recommendations for teaching practice can be developed.

Argument-Driven Inquiry

The Argument-Driven Inquiry (ADI) model, developed by Sampson, Grooms, and Walker (2011), gives students an opportunity to both engage in scientific practices and build their scientific writing skills and content knowledge, as well as their overall scientific literacy. The goals of ADI are for students to learn how to write scientifically by engaging in a realistic writing task and engaging in scientific practices, to provide students with opportunities to read good examples of these tasks that are written with the same goal in mind, to provide them with information about their own content understanding and writing quality, and to give students opportunities to revise their work (Sampson, et al., 2013).

The ADI model, as written, consists of eight steps: 1) identification of the task and research question; 2) collect and analyze data; 3) develop a tentative argument; 4) argumentation session; 5) write an investigation report; 6) double blind group peer review; 7) revise and submit the report; and 8) explicit and reflective discussion (Sampson, et al., 2013).

Cavagnetto (2010), in a study of various orientations to teaching scientific argumentation, noted that immersion in scientific practices was the most effective, suggesting that simply knowing the structure of an argument is not enough for students to be able to argumentatively. He suggests that the goal of argumentation instruction is to transfer an understanding of scientific practice, rather than just argument skills. With this understanding in mind, the ADI model gives students explicit instruction in both argument construction and scientific practice, by allowing students to construct arguments using their own data from their own investigations.

Sampson, et al. (2013) conducted a study to evaluate the effectiveness of the ADI model in science classrooms. Their study was conducted in four high school classrooms and two middle school classrooms, and the researchers assisted teachers with developing a total of sixteen labs in the ADI style and measured the gains students made in their content knowledge and their argumentative writing skills. They collected data through argumentative writing assessments and science content assessments, both graded on rubrics. Researchers found that students' ability to write scientifically and to understand science content showed a significantly large improvement when implemented consistently.

Taking this research further, Grooms, Enderle, and Sampson (2015) conducted a small-scale study that examined two high school chemistry classes in the same district, with similar demographics. One school's students participated in ADI, while the other did not. Pre- and post-assessments indicated that students in the ADI class made significant gains in their science content knowledge, scientific writing, and performance tasks, while the non-ADI class only made gains in their science content knowledge.

One issue with this model was that it is fairly extensive, and one major line of research was to determine which aspects of ADI are “nonnegotiable” to produce meaningful student learning results (Sampson, et al., 2013). Therefore, more research on the ADI model is required to determine which features of the ADI model can be modified or shortened, while still yielding meaningful benefits to students’ content knowledge and argumentative writing skills.

Problems and Challenges with Implementation

Although argumentative writing may yield many potential benefits to students, there are several obstacles to successful implementation of these practices within the science curriculum. According to Bar, Brosh, and Sneider (2016), the NGSS have established clear targets for assessment, but not a clear pathway to reach the ideals set forth in these standards. The authors of this paper focused on the development of “threshold concepts,” related to science content, that allow students a foundation for meeting the standards. The same can be argued for every area of science, including the ability to write scientifically. Bar, Brosh, and Sneider (2016) suggest that, in every area of science, teachers must work across grade levels to define these concepts and use a variety of methods to develop these concepts, knowing that they are the foundation for further science understanding. However, for many essential skills taught in science classes, this is much easier said than done.

Kiuhara, et al. (2009), in an effort to inform high school writing reform, examined writing practices used by teachers, evaluated the preparation that teachers received to teach writing, and asked questions to teachers about the importance of writing beyond high school and their students' writing attainment. Overall, the researchers found that science teachers did not require their students to do much writing, and provided very little explicit instruction on writing. They also viewed writing as less important than social studies and language arts teachers did. Potential hypotheses for this phenomenon is that science teachers may not view teaching writing as their responsibility, or that they believe that students already possess needed writing skills (Bar, Brosh, and Sneider, 2016).

This study took place before the adoption of the NGSS, and some improvements may have taken place since then in accordance with these standards. However, the statistics regarding science writing is alarming, and this may contribute to the overall issues with scientific literacy presented in the classroom. This study demonstrates why it is important for science teachers to incorporate scientific literacy within the classroom, starting at the elementary level, because it is imperative that, even if they go into a classroom later in their educations where scientific literacy is not explicitly taught, they will have some of the skills they will need to succeed in scientific writing in the future.

However, science teachers may not be emphasizing scientific literacy skills, including writing in the content area, because they might not feel qualified to do so. Demirel and Cayamaz (2015) conducted a study at Hacettepe University in Turkey aimed to examine teachers' self-efficacy in their ability to teach their students to be scientifically literate. The purpose of this study was to provide feedback to teacher training programs about potential directions for improvement in developing these self-efficacy beliefs within teachers. Responding to a "Self-Efficacy Scale in Scientific Literacy" questionnaire, prospective science and primary school teachers thought their scientific literacy abilities were on a "quite sufficient level," with prospective science teachers rating their abilities significantly higher than prospective primary school teachers, females higher than males, and science teachers of upperclassman higher than science teachers of lowerclassmen. Demirel and Cayamaz (2015) suggest that in order to increase teacher self-efficacy in science literacy, teacher training programs should provide more direct experience and chances to practice. Without this experience and practice, teachers may be more hesitant to incorporate writing into the science curriculum.

May and Wright (2007) described the Language Across the Curriculum (LAC) movement, which aimed to integrate language as a central component of all content areas in secondary schools. This program was implemented in several countries, including New Zealand. However, this interest decreased as the interest in high-stakes testing grew. While this movement was well-grounded in theory, not all schools implemented these practices. One reason may be because financial resources were not adequately allocated to support this movement. Another reason may have been the lack of teacher buy-in, which may be an issue of professional development. Furthermore, school structures need to support these initiatives. The author claims that secondary teachers are less equipped to teach literacy practices than their elementary school counterparts, and to analyze data for informing instruction. This highlights a need for secondary teachers to continue engaging in professional development that will allow them the skills to continue helping students to build their literacy skills, and for the organizational structures to ensure that these initiatives will be supported.

Summary

If teachers are able to overcome numerous obstacles to utilize the new focus on inquiry and collaborative practices to deliver instruction on scientific writing, the research demonstrates that students show improved content knowledge and improved ability to communicate scientifically through argumentative writing. With the new focus on inquiry, teachers can use inquiry-based activities as a context for these argumentative writing practices, as demonstrated in the ADI model. The use of the ADI model proved beneficial to students' learning gains, but the model is extremely extensive and difficult to implement with fidelity. Sampson, et al. (2013) and Grooms, Enderle, and Sampson (2015) both described the need to determine which aspects of the ADI model are "nonnegotiable," and can be eliminated from the teaching sequence without consequence. ADI, through its combination of scientific inquiry and argumentative writing, seems like it yields promising benefits to students' scientific argumentative writing abilities. To increase its usefulness on a wider scale, further research should be conducted to examine students' learning results when this model is modified.

Chapter 3 Method

Research Approach

This study examines the effect of inquiry-based argumentative writing exercises on student achievement in argumentative writing tasks in middle school science classes. This study was conducted as a teacher action research study. Action research is defined by MacDonald (2012) as a process that is "concerned with an agenda for social change that embodies the belief of pooling knowledge to define a problem in order for it to be resolved" (p. 36).

Data were collected from sixth-grade science classes in a public middle school located in the greater San Francisco Bay Area. The research followed a mixed-methods approach. Argumentative writing tasks were scored quantitatively, using a rubric. Rubric scores were analyzed by category (claim, evidence, and reasoning), in order to distinguish any correlations or themes, as well as direction for future writing instruction. Quantitative data was also collected from pre- and post-assessments examining students' ability to analyze written arguments (Knight, et al., 2013). This quantitative data was combined with student surveys of their own areas of ease and struggle and their evaluation of the process, as a whole.

Ethical Standards

This paper adheres to the ethical standards for protection of human subjects of the American Psychological Association (2010). This study did not need Institutional Review Board for Protection of Human Subjects (IRBPHS) review because it involved a teacher evaluating evidence of student performance within the customary activities of the classroom. The researcher was the teacher of record and received permission from the school site leadership to conduct the study. Additionally, the research project was approved by a thesis advisor.

Sample and Site

The students included in this study are sixth-grade students in a public, suburban middle school in Northern California. A total of 73 sixth-grade students participated in this study as part of the curriculum of their science class. Students ranged in age from eleven to thirteen years old. This study only included students who had either been determined to be fluent in English, or had an overall CELDT score of “Intermediate” or higher. In addition, data were only included from students that were present in class on the days that the assessments were conducted.

Access and Permissions

The students under research are assigned to a sixth-grade science class at the public middle school under study, with the researcher as the teacher of record. Data was collected as part of the science curriculum, planned by the researcher, through customary and usual practice. Permission to conduct research in the classroom was granted by the school principal prior to data collection.

Data Gathering Procedures

Since the research aimed to analyze the effectiveness of a certain series of explicit, inquiry-based writing instruction, as determined by a review of the literature, students completed two forms of assessment before and after the modified ADI instruction was used in the classroom: 1) an reading assessment that quantitatively scored their ability to identify, critique, and compare written arguments; 2) an argumentative writing sample. For the purposes of clarity, the reading assessments will be further referred to as “Assessment 1.1 (pre-assessment) and 1.2

(post-assessment), and writing samples will be further referred to as “Assessment 2.1 (pre-assessment) and 2.2” (post-assessment). Assessments 1.1, 1.2, 2.1, and 2.2, as well as the associated rubrics are derived from the “Earthquakes 1” and “Volcanoes 1” reading and writing assessments described in a study by Knight, McNeill, Corrigan, and Barber (2013) (Appendix A, Appendix B, Appendix C, Appendix D, Appendix G, Appendix H).

Assessments 2.1 and 2.2, obtained from Knight, et al. (2013), presented students with a set of data, which they used to create their own arguments (Appendix C, Appendix D). Writing samples were scored on a rubric, modified from Knight, et al. (2013), which measured student performance in the following categories: claim, evidence, and reasoning (Appendix H).

Assessments 1.1 and 1.2 and their rubrics were modified from the “Earthquakes 1” and “Volcanoes 1” assessments by Knight, et al. (2013). These assessment presented students with a set of data and a fictional student’s written argument about this data set. Students were asked two multiple-choice questions and a written response about this argument. The multiple-choice questions quantified a student’s ability to identify and critique an argument, and the written response measured their ability to compare two different arguments (Appendix A, Appendix B).

Throughout the process of instruction, students wrote argumentative paragraphs that responded to a set of data that they collected themselves, and were formatively assessed on these paragraphs. These assessments will be referred to as Assessments 3.1 and 3.2 (Appendix E, Appendix F). Students were instructed to include a claim, evidence, and reasoning in these paragraphs, and they were peer-edited on this basis before students turned in final drafts. These paragraphs were scored on the same rubric as the writing samples they wrote in their writing samples before and after instruction took place (Appendix H).

After the instructional process took place, students took a survey through Google Forms. They were asked questions about claim, evidence, and reasoning and about perceived strengths and weaknesses in their writing, in order to identify potential adjustments to this model of instruction. They were also asked about the peer-editing process, in order to identify ways that this process could be adjusted to make the feedback more useful to students.

Survey questions included the following:

1. On a scale of 1-10, how confident are you as a writer?
2. What do you find difficult about writing? (Choose one or more answers: spelling and grammar, vocabulary, putting my ideas into words, organizing ideas into paragraphs, topic and conclusion sentences, facts and evidence, details and reasoning, transition words, understanding the question, other.)
3. What do you find easy about writing (Choose one or more answers: spelling and grammar, vocabulary, putting my ideas into words, organizing ideas into paragraphs, topic and conclusion sentences, facts and evidence, details and reasoning, transition words, understanding the question, other.)
4. On a scale of 1-10, how confident are you about the paragraph you just wrote? Explain your answer.
5. On a scale of 1-10, how useful were the peer edits?
6. Approximately what percentage of the peer feedback did you use to improve your writing? (90-100%, 80-89%, 70-79%, 60-69%, 50-59%, 50% or less)
7. Explain your two above answers.

8. When writing paragraphs in the future, do you think we should peer-edit again? Why or why not?

9. In a short sentence or phrase: What is a "claim"?

10. In a short sentence or phrase: What is "evidence"?

11. In a short sentence or phrase: What is "reasoning"?

Data Analysis Approach

Assessments 1.1 and 1.2, conducted before and after the series of instruction, consisted of two multiple-choice questions and a written response, which was scored on a rubric, obtained from Knight, et al. (2014). Scores were sorted and analyzed by student, in order to distinguish any change in achievement. The first multiple-choice question, measuring students' ability to identify an argument in a writing sample, asked students to identify an additional piece of evidence that the fictional student could use to strengthen his argument. The second multiple-choice question provided students with an additional piece of evidence, and, as a measurement of the student's ability to critique the quality of the evidence, asked whether or not the student could include this evidence in their argument, and why. The written response prompt provided students with another fictional student's argument about the same data set, and asked students to compare the two arguments to see which argument uses stronger evidence. The "identify" and "critique" questions were scored on the basis of correctness, and the written response was scored on a rubric with scores ranging from 0 to 3. A score of 0 indicated no answer or an incorrect comparison. A score of 1 indicated either a correct choice with no reasoning or a correct choice with incorrect reasoning. A score of 2 indicated that the student made a correct choice and critiqued the evidence used in only one of the arguments. A score of 3 indicated that the student made a correct choice and critiqued the quality of the evidence used in both arguments (Appendix G).

All writing samples; which included Assessments 2.1 and 2.2, conducted before and after instruction, as well as the formative writing assignments given during the series of instruction, Assessments 3.1 and 3.2; were scored on a rubric, modified from rubrics by Knight et al. (2013) and Wheeler-Toppen (2012, p. 33). The quality of writing was scored in the following categories: claim, evidence, and reasoning (Appendix H). Scores were analyzed by category, in order to determine any recurring patterns to changes in student achievement between the pre- and post-assessment.

Qualitative assessment data were collected and compared to students' paragraph scores. This comparison was meant to elucidate any widespread areas of confusion, and how any difficulties reflected in students' writing samples. Since the purpose of this study was to create a regularly usable and useful ADI modification, this feedback was used to determine future areas for improvement to this instructional model.

Chapter 4 Findings

Description of Site, Individuals, Data

Research Context and Participants

The setting of the study was a suburban public school in Northern California. The participants of this study were sixth-grade students, ranging from 11 to 13 years of age. This study was conducted as part of the sixth grade science curriculum, as part of a unit on human body systems. The science department under study is in the midst of transitioning to and implementing the NGSS, and the district's middle schools are following the California Integrated Learning Progressions Model, as described in Appendix K of the NGSS (NRC, 2013, p. 21). The teacher implementing this study has received training in how to implement classroom practices that support the NGSS.

Sixth-grade students have been participating in various labs throughout the school year, and the analysis has taken the form of answering specific questions about the lab and about the data collected. They had received only cursory instruction on how to create a claim, to collect evidence, and to provide reasoning for their evidence. These factors, until the time of this study, had been used in the context of developing arguments based on research or analyzing an author's argument, rather than creating their own arguments from their own data collection.

Description of Student Activities

Students engaged in a process loosely based on the Argument-Driven Inquiry (ADI) Model, developed by Sampson, et al., 2013. This model follows the following strict series of instruction: 1) identify the task and research question; 2) collect and analyze data; 3) develop a tentative argument; 4) conduct an argumentation session; 5) write an investigation report; 6) conduct double blind group peer review; 7) revise and submit the report; and 8) participate in explicit and reflective discussion (Sampson, et al., 2013).

Preceding the sequence of instruction, students took a pre-assessment that was divided into two components: written argumentative writing and argument analysis. Pre-assessments were administered approximately a month prior to the lab activities under study.

Students participated in three different labs designed to follow the ADI model in an age-appropriate and time-conserving manner. Each lab took approximately two days, and proceeded according to the same general sequence, modified from the original ADI model, as follows: 1) identify the task and research question; 2) collect data; 3) draft “claim”; 4) participate in class-wide argumentation session; 5) write argumentative paragraph, using claim, evidence, and reasoning; 6) participate in peer edit; 7) revise and submit the paragraph; 8) participate in reflective discussion throughout instruction.

Since the content covered at the time of the study related to human body systems, the labs in this model covered content related to two different body systems: the circulatory system and the nervous system. These labs both preceded the initial introduction of the body system in question, which facilitated students’ inquiry and gave them specific phenomena to reference as they learned the content.

The first lab posed the following research question: “Does a person’s reaction time depend on their age?” In a measure of reaction time, students paired up, unexpectedly dropped a meter stick into their partner’s hand, and measured the distance the meter stick fell before their partner caught it. Students recorded their answers on the board, sorted by age: 11-year-olds, 12-year-olds or older, and adults, and calculated average distances for each category, with shorter distances indicating faster reaction time. Before drafting a paragraph, the class had a preliminary discussion about nervous system tasks and how the nervous system influences the body's sensation and response to change.

The second lab in question examined the circulatory and respiratory systems, with the research question, "How does exercise affect heart rate and respiratory rate?" After being taught how to measure pulse using the carotid and radial arteries and how to count breaths to measure respiratory rate, students participated in two rounds of four different activities: sitting, running in place, jumping jacks, and chair steps. During the first round, they calculated their heart rate in beats per minute and their respiratory rate in breaths per minute, by counting either heartbeats or breaths for fifteen seconds, and multiplying by four to get the per-minute rate. Students drafted paragraphs following a discussion about the functions and purposes of the circulatory and respiratory systems.

Students were provided with a brainstorm scaffold on which to structure their paper. The scaffolded contained the following sections: claim (answer to the essential question), evidence (numbers from data table), and reasoning (scientific facts to explain evidence). Following discussion of data, students were instructed to take approximately two minutes to draft a claim to answer the research question. Following this, students participated in a modified argumentation session.

In the ADI model, argumentation sessions consist of groups sharing their arguments with the class, while their classmates ask questions and offer critiques (Sampson and Grooms, 2013, p. 651). In this study, the argumentation session consisted of students discussing their drafted claims with one another. They were expected to share with their team their own answer to the research question. They were also expected to have a tentative reason why they had arrived at this conclusion – either specific numbers from their data collection or scientific reasoning based on knowledge of the content material. Then, students were randomly called on to share both their claim and the reason why they answered the research question in this way. Following this discussion, students used the scaffold to gather their thoughts, and then drafted their paragraphs.

Following the drafting of their argumentative paragraph, students participated in peer editing of these paragraphs. Students received a rubric to tape into their science notebooks, next to their draft. Rather than doing a double-blind peer review, students simply traded notebooks with someone else in the classroom and filled out each other's "Peer Edit Checklists" (Appendix I). Students were expected to rate and indicate the presence and specificity of a claim, the presence and specificity of at least two pieces of evidence, and the clarity of the reasoning behind the evidence. Students also provided their partners with specific "likes" and "wonders" about their paragraphs. After rubrics were passed back, students were given a chance to edit their paragraphs as they revised and turned them in via Google Classroom. Following this process, these labs were continually referred to as discussion of the science content continued.

Following the sequence of instruction, students completed two post-assessments, nearly identical to the pre-assessments, measuring their abilities to both analyze and write arguments. This assessment allowed for an analysis of individual growth that may have stemmed from the modified ADI process.

In addition, through a Google Form, students completed a reflective survey on their attitudes toward writing, as well as their strengths and weaknesses as writers. They described the peer-editing process, indicated its usefulness for their writing. Furthermore, as a check for understanding, they described each of the three terms in a short sentence or phrase: "claim," "evidence," and "reasoning."

Themes

Data analysis revealed the following themes that apply to the impact of inquiry-based argumentative writing instruction in the middle school science classroom:

1. Inquiry-based argumentative writing instruction increases students' ability to identify, critique, and compare the quality of evidence in written arguments.
2. Participation in inquiry-based argumentative writing exercises helps to strengthen students' scientific claims.
3. Students' writing scores increase when scaffolded to meet expectations.
4. Students need continuous feedback in order to improve as writers.

Theme 1: Inquiry-Based Argumentative Writing Instruction Increases Students' Ability to Identify, Critique, and Compare the Quality of Evidence in Written Arguments

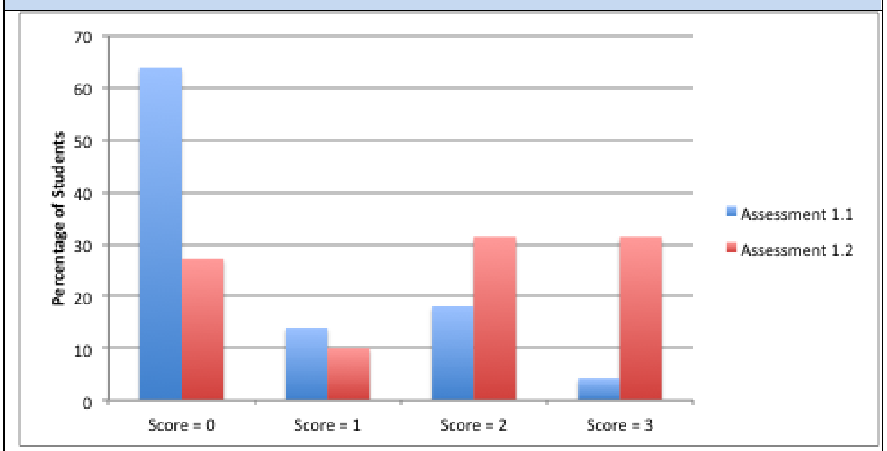
The reading assessments (Assessment 1.1 and 1.2) measured students' abilities to analyze arguments on three different levels: Identify, Critique, and Compare and Critique. Knight, et al. (2013) describe these levels of achievement on a construct map that demonstrates students' progression toward deeper analysis of arguments that they read. Students' ability to identify arguments was measured through a multiple-choice question. Their ability to critique arguments was measured on two levels: through a second multiple-choice question and through a free response answer. Finally, this assessment measured students' capacity to compare and critique arguments through the same free-response answer, which was scored on a rubric of 0 to 3. Scores of 0 indicate an incorrect comparison choice, scores of 1 indicate a correct choice, scores of 2 demonstrate the ability to critique one argument, and scores of 3 demonstrate the ability to critique and compare two arguments (Appendix G). Assessment 1.1 was administered prior to sequence of argumentative writing instruction under research, and Assessment 1.2 was administered following this instruction.

Table 1.1 describes students' demonstration of argument analysis skills on Assessments 1.1 and 1.2. Table 1.2 describes students' performance on the free-response question on Assessments 1.1 and 1.2, and Figure 1 illustrates this same data. Percentage points refer to students who responded to the assessment in a way that demonstrates possession of a particular skill. Only students who were present on the day this assessment was administered were included in the data collection process.

TABLE 1.1 – Students Demonstrating Argument Analysis Skills on Reading Assessments (Assessments 1.1 and 1.2)				
	Identify	**Critique (Multiple-Choice)**	**Critique (Free Response)**	**Compare and Critique**
Assessment 1.1 (Pre-Instruction; 72 students)	47.2%	48.6%	18.1%	4.2%
Assessment 1.2 (Post-Instruction; 70 students)	67.1%	50%	31.4%	31.4%
Difference	19.9%	1.4%	13.3%	27.2%
P-Value "N-1" Chi-Squared Test	0.0170	0.8680	0.0670	P<0.0001

TABLE 1.2 – Demonstration of Student Skills in Free Response Question of Assessments 1.1 and 1.2				
	Score = 0 Incorrect Choice	**Score = 1 Correct Choice**	**Score = 2 Critique**	**Score = 3 Compare and Critique**
Assessment 1.1 (Pre-Instruction; 72 students)	63.9%	13.9%	18.1%	4.1%
Assessment 1.2 (Post-Instruction; 70 students)	27.1%	10.0%	31.4%	31.4%
Difference	36.8%	3.9%	13.3%	27.3%
P-Value "N-1" Chi-Squared Test	P<0.0001	0.4758	0.0670	P<0.0001

FIGURE 1: Distribution of Student Free-Response Scores (Assessments 1.1 and 1.2)



The skill of comparing and critiquing evidence within an argument demonstrated the greatest improvement, with a difference of 27.3% between Assessments 1.1 and 1.2. In contrast, the smallest amount of growth occurred with the skill of critiquing evidence within the context of a multiple-choice question, with a difference of 1.4% between the two assessments.

In Assessments 1.1 and 1.2, the ability to critique evidence within an argument was evaluated in two separate questions – one multiple choice and one free response. Assessment 1.1

showed a notable difference between those two questions: 48.6% of students were able to critique the evidence in the multiple choice question, but in the free response question, only 18.1% of students showed this skill. Similarly, in Assessment 1.2, 50% of students were able to critique evidence through the multiple-choice question, versus 31.4% through the free response. Of note, in Assessment 1.1, a total of 22.3% of students were able to either critique or compare and critique evidence in the free response question, and in Assessment 1.2, 62.8% of students demonstrated this skill, which was a statistically significant ($p<0.0001$) increase.

Prior to this sequence of instruction, students had received only cursory instruction on what constituted a “claim,” “evidence,” and “reasoning.” Through the process of constructing lab reports, students had to create their own claims, collect their own evidence in the form of measurements, and supply reasoning in the form of data analysis and scientific facts. Assessments 1.1 and 1.2 measured students’ ability to identify, compare, and critique evidence. Two of these skills demonstrated statistically significant improvement – the ability to identify supporting evidence and to compare and critique the use of evidence between two arguments.

In the ADI model, as well as in the modified model of instruction, students conduct their own labs and choose relevant data from their sets to support their arguments. From this data, it can be concluded that this student collection of data with which to write the lab reports supports their ability to identify relevant supporting evidence to support a claim. During this sequence of instruction, students collected data to support the claims they made throughout the process of the lab. The lab in Assessment 3.1 included a smaller data set that necessitated the use of all data to support the claim. However, during the experiment written about in Assessment 3.2, students had a large set of data to choose from, only some of which was necessary to support a claim, and students were encouraged to pick and choose what was necessary and relevant.

Furthermore, students, as a whole, were better able to compare and critique the use of evidence in multiple arguments. This may also be attributable to the picking and choosing of relevant evidence to include in their lab reports, and it may also be a result of the peer review process, where they had to critique a partner's use of supporting evidence. It might also be due to the increased use of evidence, itself, in their classroom activities. A common observation in Assessment 1.1 was that, when students were comparing two arguments in the free response question, several students chose the wrong argument as more effective because the writing was more "specific" and "detailed." The use of evidence in their own lab reports may have allowed them to better interpret the quality of this evidence, rather than rely on their perception of the amount of detail or the quality of writing in the argument. Furthermore, though engaging in peer-editing of their formative paragraphs, students were trained to examine the quality of evidence and writing used in other people's writing, which may have also supported this skill. It can be hypothesized that, as students are trained to choose between various data points to support claims, they will be better able to utilize this skill in novel situations.

The ability to either critique an argument or compare and critique multiple arguments in the free response question showed a statistically significant increase, whereas the ability to critique in a multiple choice question did not. An interesting observation is that, in Assessment 1.1, far fewer students were able to either critique or compare and critique arguments in the free response question, whereas the trend reversed in Assessment 1.2, where more students were able to clearly write about their critique and comparison in the free response than convey a correct critique in the multiple choice question. This may have been due to the fact that, in Assessment 1.1, they did not have a full understanding of the significance and meaning of scientific evidence. By the time they took Assessment 1.2, they had been exposed to scientific evidence through the modified ADI activities and lab reports in class. This practice with writing about their own evidence may have allowed them to express their ideas more clearly in words than through a multiple choice question. Nevertheless, this data demonstrates an increase in students' ability to analyze the quality of the evidence used in an argument.

These results demonstrate that the process of collecting and writing about data is helpful in helping students distinguish appropriate data to use in an argument, critique the quality of this data, and compare the quality of multiple arguments that utilize slightly different data. In the classroom lab activities, almost all data that students collected were relevant and appropriate to use as evidence in their lab reports. If this were to not be the case, and some student data were to be irrelevant to their arguments, it is unclear what impact this might have on the results. However, these results can conclude that the process of collecting and writing about data in lab reports positively impacts students' ability to identify evidence, as well as to critique evidence and compare and critique the quality of evidence in multiple arguments.

Theme 2: Participation in Inquiry-Based Argumentative Writing Exercises Helps to Strengthen Students' Scientific Claims

Students wrote a total of four separate paragraphs throughout the course of this study. Assessments 2.1 and 2.2 were summative tasks that measured students' ability to interpret data in writing, using claim, evidence, and reasoning, before and after the instructional sequence. Assessments 3.1 and 3.2 were formative lab reports, written as part of the instructional sequence, where students were guided to write similar paragraphs that drew conclusions from their own data sets collected during labs.

Paragraphs were graded on a rubric that measured the quality of students' use of claim, evidence, and reasoning. Each category was graded on a scale of 0 to 3, based on a set of rubric criteria (Appendix H). Table 2 depicts the average student performance on all three categories of Assessments 2.1 and 2.2.

TABLE 2 – Student Average Performance on Summative Writing Assessments (2.1 and 2.2)			
	Claim (Score 0-3)	**Evidence** (Score 0-3)	**Reasoning** (Score 0-3)
Assessment 2.1 (Pre-Instruction; 73 students)	1.178	0.932	0.877
Assessment 2.2 (Post-Instruction; 70 students	1.514	1.071	0.971
p-value (2-tailed test, 5% significance)	0.025	0.441	0.547

The scores on Assessment 2.2, conducted post-instruction, exceeded those on Assessment 2.1. On average, students scored 0.336 points higher on the quality of the claim, 0.139 points on evidence, and 0.094 on reasoning. Although all categories showed an increase, only the differences in the claim were statistically significant, with a p-value of 0.025.

Students demonstrated a relative strength in including clear claims in arguments, with an average score of 1.343 in summative assessments and 2.094 in formative assessments. On the other hand, students seemed to struggle with including strong, relevant reasoning that connected their evidence to their claims. The reasoning category had a formative average of 1.647 and a summative average of 0.923.

Although all three categories on the rubric demonstrate increases in student scores, only the claim category showed a statistically significant increase. Therefore, this is the only category that can be considered as having been impacted by the modified ADI instruction presented in the science classroom.

Part of the instructional sequence included an “argumentation session” that had been modified from the original ADI model. In this research, the argumentation session consisted of students being given time to silently draft a claim, described as an answer to the research question, in their science notebooks. Students were then given time to discuss their drafted claims with one another, by sharing their own claim, as well as at least one reason why they had arrived at this conclusion – either specific numbers from their data collection or scientific reasoning based on knowledge of the content material. Then, students were randomly called on to share both their claim and why they chose that claim.

In this argumentation, students were required to enter the discussion with a strong, clear claim. This discussion helped to ensure that every student had a claim, and that each student was able to construct this claim as instructed – answering the question and taking a clear position, based on the data that they had collected. The discussion of the evidence and the reasoning were less structured. The focus of this argumentation session was to ensure that students had a claim, and some reason why they made that claim. Therefore, this argumentation session served as a check on the quality of the claim, rather than the evidence and reasoning behind it. If students had followed a similar discussion process addressing the use of evidence and reasoning, they may have been able to demonstrate this knowledge more effectively on assessments.

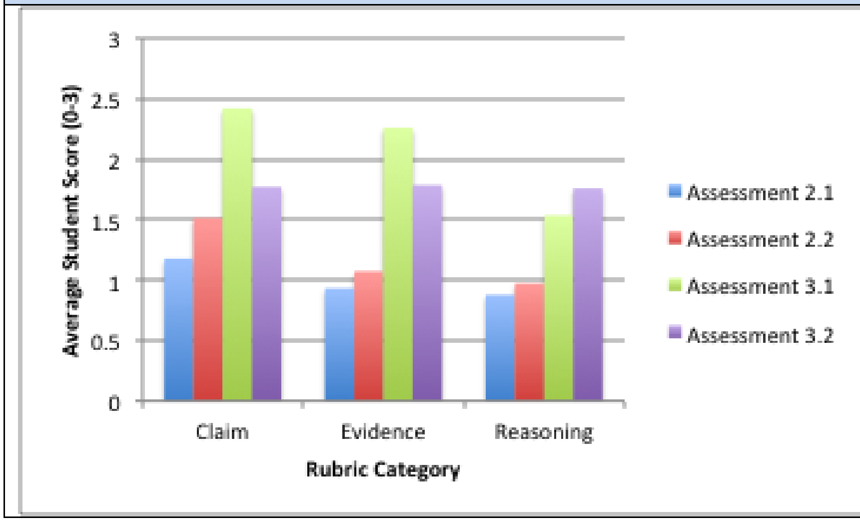
Theme 3: Students’ Writing Scores Increase When Scaffolded to Meet Expectations

Table 3.1 depicts data on Assessments 3.1 and 3.2, which were formative lab reports written during the series of inquiry-based writing instruction. These reports were scored in the areas of claim, evidence, and reasoning, on the same rubric as Assessments 2.1 and 2.1. Table 3.2 compares the average formative assessment data from Assessments 3.1 and 3.2 with the summative assessment data collected from Assessments 2.1 and 2.2. Figure 2 compares all four assessments in the three categories scored on the rubric.

TABLE 3.1 – Student Average Performance on Formative Writing Tasks, by Category (3.1 and 3.2)			
	Claim (Score 0-3)	**Evidence** (Score 0-3)	**Reasoning** (Score 0-3)
Assessment 3.1 (69 students)	2.420	2.261	1.536
Assessment 3.2 (70 students)	1.771	1.786	1.757

TABLE 3.2 – Average Student Scores on Summative vs. Formative Writing Tasks (Assessments 2.1, 2.2, 3.1, and 3.2)			
	Claim (Score 0-3)	**Evidence** (Score 0-3)	**Reasoning** (Score 0-3)
Formative Average (3.1 and 3.2; 139 samples)	2.094	2.022	1.647
Summative Average (2.1 and 2.2; 142 samples)	1.343	1.000	0.923
Percent Difference	43.7%	67.6%	56.3%
p-value (2-tailed test, 5% significance)	$P<0.001$	$P<0.001$	$P<0.001$

FIGURE 2: Comparison of Student Scores (Assessments 2.1, 2.2, 3.1 and 3.2)



Unsurprisingly, the scores on the formative assessments (3.1 and 3.2) exceeded the scores on the summative assessments (2.1 and 2.2) in all three categories, by significantly large margins. When taken together, the difference between the evidence on the summative versus the formative assessments was the most striking, with a percent difference of 67.6%. The reasoning, the overall weakest category, also showed a dramatic 56.3% difference between the summative and formative assessments, with an average of 1.047 for the formative assessments and 0.923 for the summative assessments. Similarly, the formative evidence scored 2.022, while the average summative evidence was 1.000. The average claim on the formative assessments was 2.094, which was 43.7% higher than the average summative claim of 1.343.

When writing the two formative paragraphs, students were expected to plan out their paragraphs on a notebook scaffold prior to drafting their paragraph. The scaffold consisted of three boxes; claim, evidence, and reasoning; with the terms defined next to the planning space. Since each rubric category was separated on the notebook scaffold, students were able to mentally distinguish between the three components of scientific argumentative writing. This scaffold also indicated to them that when drafting these paragraphs, the inclusion of all three components was an expectation. In contrast, when presented with data for the two summative assessments, students were not given any kind of scaffold; they were merely presented with lines to write on. Even though some students were able to transfer these skills, and all three components demonstrated some improvement between Assessments 2.1 and 2.2, the inclusion of all three components were not an obvious expectation for the assignment, even though the students may have possessed the skills to do so.

The difference between the use of evidence in the formative versus the summative assessments was very striking, with a 67.6% difference in scores between the two assessment types. One potential reason for this difference was the student familiarity with the data. In the summative writing assessments, students were presented with a data table to interpret, with no previous knowledge about the data. In contrast, students had collected data in class in order to write their formative lab reports. Students had an intimate knowledge about the data for these paragraphs because they had collected it. They were able to engage in competition for a faster reaction time and they were able to experience an increase in heart and respiratory rate in their own bodies, when they exercised. Therefore, when expected to write evidence-based paragraphs about these phenomena, they were extremely familiar with the data and what it meant for their own bodies. However, the summative assessments were about earthquakes and volcanoes, neither of which students had learned about in class, and neither of which students had collected their own data about. Therefore, the evidence did not carry as much of a meaning for them.

Furthermore, student participation in a peer-review process when drafting their lab reports may have also increased the quality of the claim, evidence, and reasoning. Students were provided with a checklist to use when reading another person's paragraph (Appendix I). This checklist specifically asked students to critique the quality of their classmate's claim, evidence, and reasoning. There was also space provided where students could indicate things they liked about their partner's paragraph, as well as "wonders" for things they could have done differently. The peer review may have been a factor that helped to increase the quality of formative student paragraphs in comparison to the summative assessments.

The vast difference between the quality of the formative paragraphs and the summative assessments illustrate that students at this grade level require significant scaffolding in order to successfully write a scientific argumentative paragraph. In this series of instruction, the argumentation session, the planning worksheet, and the peer review process may have provided this support. When delivering instruction on argumentative writing, teachers need to consider techniques that they are using to give students the support they need to succeed.

Theme 4: Students Need Continuous Feedback In Order To Improve as Writers

Students participated in an in-class survey after this inquiry-based series of argumentative writing instruction. This survey required students to indicate their strengths, weaknesses, and comfort as a writer. They used a Google Form to rate their confidence on a scale from 1-10. In addition, they were provided with a series of checkboxes of common aspects of writing, and asked to indicate which factors they found easy and which they found difficult. Figure 3 illustrates the overall distribution of student confidence levels in their writing. Figure 4 depicts common areas of difficulty, and Figure 5 shows common areas of strength. Table 4 quantifies and compares specific student responses about their strengths and weaknesses.

FIGURE 3: Student Responses to the Question: "On a scale of 1-10, rate your confidence as a writer."

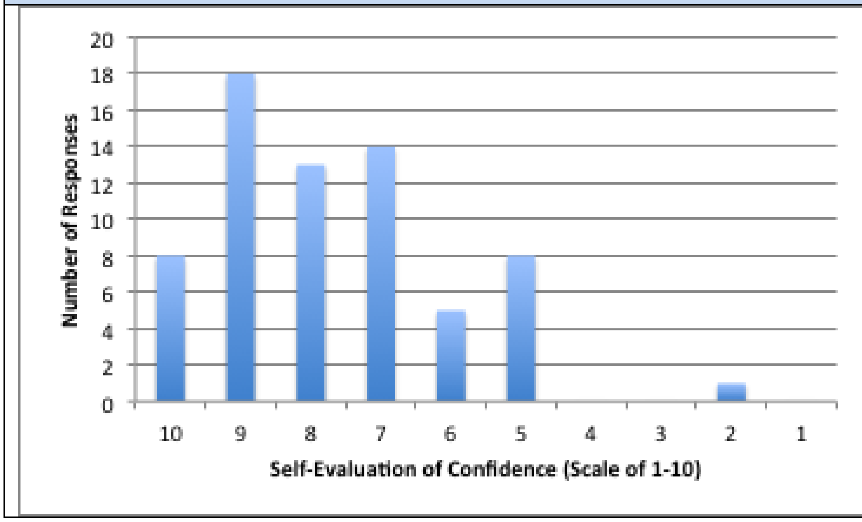


FIGURE 4: Student Responses to the Question: "What do you find difficult about writing?"

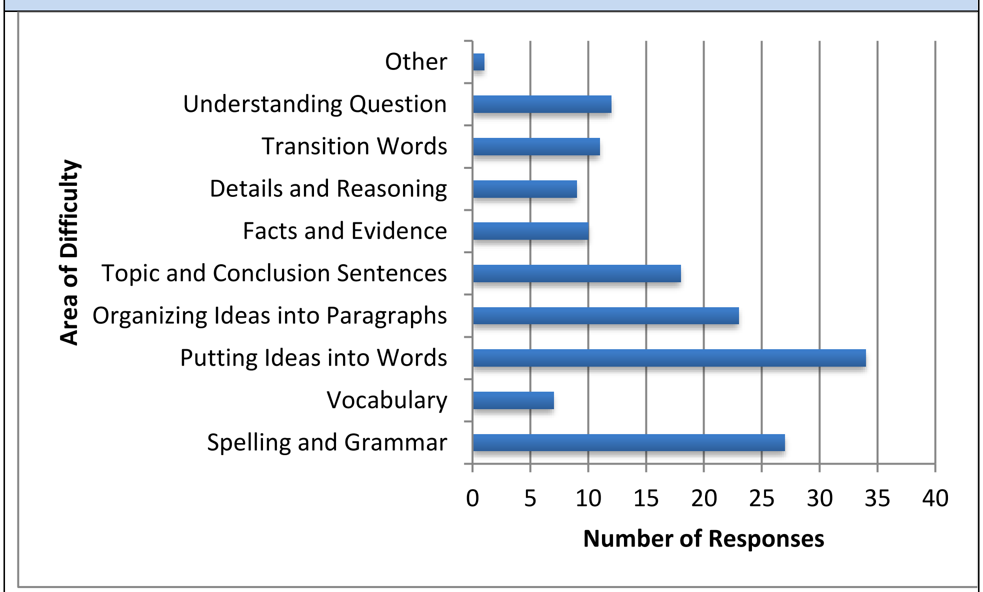


FIGURE 5: Student Responses to the Question: "What do you find difficult about writing?"

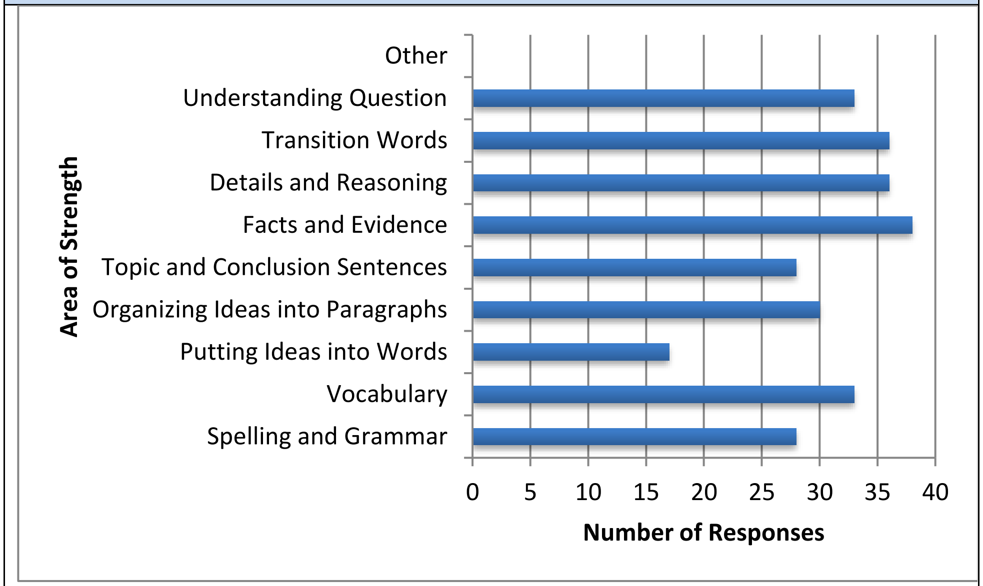


TABLE 4 – Comparison of Student Self-Reported Strengths and Weaknesses				
	Difficulty (# of responses)	**Difficulty** (% of students)	**Strength** (# of responses)	**Strength** (% of students)
Spelling and Grammar	27	40.9%	28	41.9%
Vocabulary	7	10.6%	33	49.3%
Putting Ideas into Words	34	51.5%	17	25.4%
Organizing Ideas into Paragraphs	23	34.8%	30	44.8%
Topic and Conclusion Sentences	18	27.3%	28	41.8%
Facts and Evidence	10	15.2%	38	56.7%
Details and Reasoning	9	13.6%	36	53.7%
Transition Words	11	16.7%	36	53.7%
Understanding Question	12	18.2%	33	49.3%
Other	1	1.5%	0	0%
TOTAL RESPONSES	152		279	

Of note is students' overall high level of confidence in themselves, as writers. Of the 67 students polled, 79% rated their confidence as a "7" or higher. Students were allowed to check multiple boxes as "strengths" and "weaknesses." In total, students indicated 279 separate strengths and only 152 weaknesses.

The most common self-indicated areas of strength were, interestingly enough, facts and evidence, with 56.7% of students indicating this as a strength, details and reasoning (53.7%), transition words (53.7%), vocabulary (49.3%), and understanding the question (49.3%). The most common self-indicated areas of difficulty were putting ideas into words (51.5%) and spelling and grammar (40.9%), which was also indicated as a common area of difficulty (41.9%).

A significant finding of this survey was that, even though students were, as a whole, very confident in their ability to incorporate evidence and reasoning into their writing, assessment scores in these areas were relatively weak in both summative writing assessments. On Assessment 2.1, with rubric scoring on a scale of 0 to 3, students scored an average of 0.932 for evidence and 0.877 for reasoning. On Assessment 2.1, while students fared somewhat better, scores were an average of 1.071 for evidence and 0.971 for reasoning. Although scores were better on the formative assessments, these scores, when compared to students' self-evaluations, indicate that students' perceptions of their strengths differs from their performance.

The only way that students' perceptions can match their performance is if they are receiving frequent, comprehensive feedback on their writing. Although they participated in peer-editing during the instructional sequence, the usefulness of this feedback varied between students. In a survey, students were asked to rate the usefulness of this peer feedback on a scale of 1-10. Figure 6 illustrates the distribution of student responses. In addition, they were asked to choose approximately how much of the feedback they actually incorporated into the final drafts of their lab reports. Student responses are illustrated in Figure 7.

FIGURE 6: Student Responses to the Question: "On a scale from 1-10, how useful were the peer edits?"

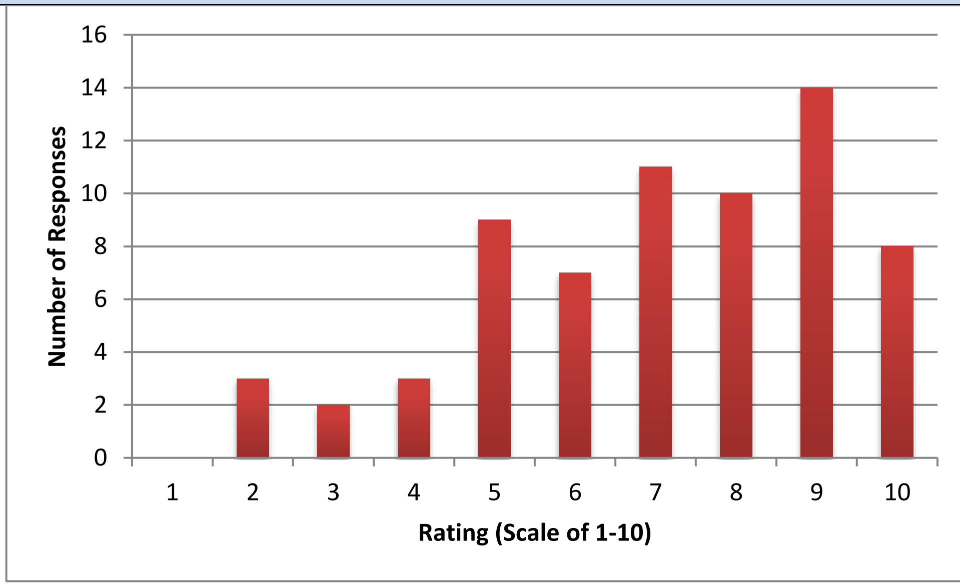
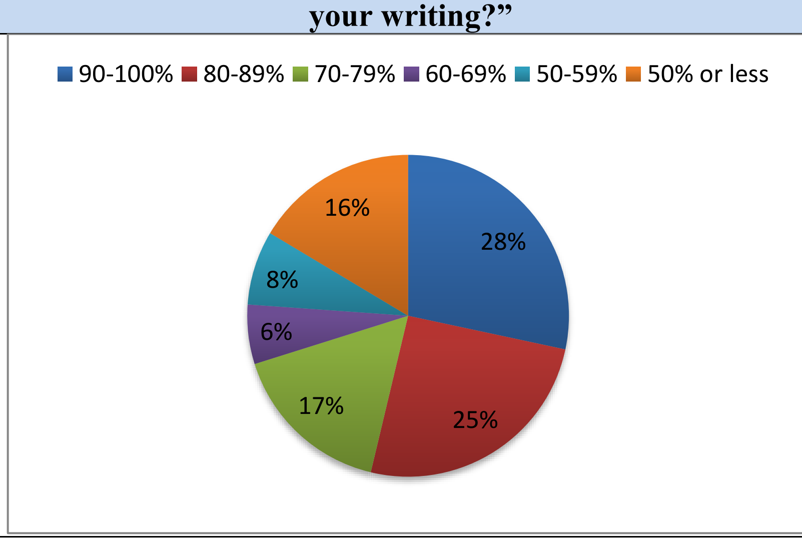


FIGURE 7: Student Responses to the Question: "Approximately what percentage of the peer feedback did you actually use to improve your writing?"



When asked about the usefulness of the peer edits, there was a wide distribution of opinions. The majority of students indicated that, on a scale of 1 to 10, 10 being the most useful, the peer feedback was a 6 or higher. The majority of students (53%) found the peer feedback useful, and incorporated between 80% and 100% of the feedback they received in order to improve their own writing. However, 25.4% of students rated this process at a 5 or lower, and 16% of students indicated that they used 50% or less of the feedback they received.

When given a chance to comment on the peer editing process, this is a sample of what some students said:

- "I wish my editor could have put more wonders because I wanted to know what to do better, not just know what I did well."
- "I found the peer editing successful. I like being able to get a classmate's perspective on my own personal writing. Although since they are not professionals, it would be nice to get some feedback from a teacher."
- "The peer edits were really good for me because I got to see what is wrong, or if something is wrong with my work. If it was, I would be able to fix it. The percentage I used (70-79) to improve my writing was mainly because of the confidence I have due to having close to nothing wrong."
- "When I have a partner edit my work, there wasn't many changes to make. I'd like if a teacher would help to give me transition words or replacements."

- “I didn’t always change exactly what my partner said to do but it made me realize that I needed to change something. Correcting someone else’s paragraph also gave me some ideas of what to add and/or change to mine.”
- “The peer edits can be useful, but in my experience, people don’t always listen to feedback, or feedback given can be unhelpful/useless.”
- “My peer didn’t give any feed back she just wrote that it was perfect.”
- “I understand what they’re telling me, but at the same time I don’t. I can’t really explain it.”
- “Peer feedback isn’t as useful as it might be for others.”

In summary, student feedback on the peer editing process indicated the following: Overall, the process of peer editing is useful for most students. However, there were students who did not receive helpful feedback and were not able to incorporate it. Upon review of the comments on the peer editing process, peer editing seemed to be less helpful for students who were already proficient and/or confident in their own writing. Even for those students, correcting someone else’s paragraph can give ideas on what can be added or changed to their own paragraph. However, in order for peer feedback to be more useful to all students, students may need some ideas on what to say to peers whose paragraphs seem “perfect” at first glance. This may involve some additional instruction on editing for ideas and their clarity, not just spelling and grammar. In addition, some accountability systems might need to be put into place for peer editing processes in order to ensure that students are putting their best effort into their feedback and taking received feedback into account.

As several students said, the best way to ensure that all students receive helpful feedback on their writing is if the teacher provides this insight. This is often a logistical impossibility before a student turns in a final draft, so peer feedback can be put into place as a proxy, as long as students are given clear, detailed instruction on how to deliver the type of feedback that is desired, and possibly even held accountable for the quality of their feedback. However, there truly is no replacement for a set of experienced eyes that have a clear idea of the expectations for a piece of scientific writing. In order for students to improve their writing, continuous, thorough feedback must be given frequently in order for students to clearly identify what they are doing right or wrong, and to engage in the metacognitive processes necessary for continued growth as a writer and a scientist.

Summary

Through implementation of an inquiry-based model of argumentative writing instruction, students became better able to identify, critique, and compare and critique the quality of evidence in written arguments. Throughout the series of instruction, they were surrounded by different forms of evidence, some of which they participated in collecting. Through incorporating that evidence into their writing and critiquing the quality of this evidence in others' writing, their ability to analyze and interpret evidence in others' writing increased. Students also became more skilled in constructing scientific claims. Participation in "argumentation sessions" where they were expected to construct, share out, and listen to other people's claims helped to increase their understanding of how to correctly write one. When students were assessed on their ability to write paragraphs including claim, evidence, and reasoning, formative assessments that incorporated their own data and were scaffolded to these expectations scored higher in each of these categories than did the assessments where they were expected to use a provided set of data to construct an argument without any assistance, which indicates that students need significant teacher support and scaffolding until they are able to meet these expectation on their own. Furthermore, although the peer feedback was helpful, student perceptions of their own abilities and commentary on the peer editing process indicated that feedback needs to be clear, thorough, and continuous for it to lead to meaningful improvement in writing.

In summary, effective scientific argumentative writing instruction needs to incorporate data that is personally meaningful to students. Argumentation sessions need to allow for student feedback on evidence and reasoning, as well as claims. The writing of lab analyses needs to be scaffolded to student areas of need. Peer feedback, if included, needs to be meaningful, and clear expectations for students’ feedback need to be in place to make it useful for all students, not just those who need a lot of support with writing. Better yet, teachers need to be involved in giving students feedback.

Chapter 5 Discussion /Analysis

Summary of Major Findings

This research incorporated an inquiry-based series of argumentative writing instruction, modified from the ADI model. This model of instruction incorporated student collection of data, followed by an argumentation session that focused on student claims, or conclusions, from their data. Following the argumentation sessions, students drafted a lab report. Once the lab report was written, students engaged in a peer review prior to writing the final draft of the lab report.

Qualitative and quantitative data collected before, during, and after this series of instruction indicate the following themes:

1. This model of inquiry-based argumentative writing instruction strengthens students' ability to identify, critique, and compare the quality of evidence in written arguments.
2. Participation in inquiry-based argumentative writing exercises helps to strengthen students' scientific claims.
3. Students' writing scores increase when scaffolded to meet expectations.
4. Students need continuous feedback in order to improve as writers.

Overall, students demonstrated a conclusive increase in ability to identify, critique, and compare the use of evidence in written arguments. Changes in the ability to incorporate claim, evidence, and reasoning into written paragraphs was less conclusive, but there was a significant increase in students' ability to write clear, conclusive claims. However, scores on formative writing tasks were much higher than those on summative writing tasks without any scaffolding, which indicates that students are able to more closely meet argumentative writing expectations with assistance and data that carry some degree of personal meaning. Furthermore, peer editing strategies proved useful for most students, but student feedback indicated that they would be more useful if students could provide more meaningful feedback and if they incorporated some degree of teacher feedback.

Based on this analysis, argumentative writing instruction can be most useful for students if it meets the following criteria:

1. Incorporation of data sets that carry meaning for students
2. Writing tasks that are scaffolded to areas of student need
3. Argumentation sessions or class discussions that focus on all three areas of scientific argumentative writing construction: student usage of claim, evidence, and reasoning
4. Meaningful feedback from both peers and teachers, and clear, concrete expectations for student provision of feedback to others

Comparison of Findings to the Literature

A review of the literature revealed several themes. Each of these themes will be discussed in relation to the results of this research.

First of all, the literature indicated that the NGSS and the CCSS have altered the roles of inquiry and collaboration in the science curriculum, which affect the manner in which writing skills can be taught. Furthermore, the literature outlined the role of inquiry as a teaching tool to further understanding of science concepts. In the NGSS, inquiry is included as part of the content standards, rather than as a separate list of standards. According to Bowman and Govett (2015, p. 55), the NGSS prioritize skills such as “technical reading, interpretation, critical thinking, and analysis” rather than memorizing science facts. Wilcox, Kruse, and Clough (2015) further this notion, suggesting that in order to incorporate inquiry into the classroom, teachers should plan instruction to promote scientific practices such as asking testable questions, creating and carrying out investigations, analyzing and interpreting data, drawing warranted conclusions, and constructing explanations that promote a deep conceptual understanding of fundamental science ideas" (p. 62).

This research acknowledges investigation, data analysis, and scientific writing as an essential part of science instruction under NGSS, and the argumentative writing instructional series under investigation incorporates several of the inquiry practices outlined by Wilcox, Kruse, and Clough (2015). The data from this research also concluded that, in order for students to be able to engage in scientific argumentative writing, the data need to carry some degree of personal meaning. This familiarity allows for more accurate interpretation and reasoning. In conjunction with direct instruction, students will be better able to analyze and interpret their own data, as opposed to a fictional set of data. This finding emphasizes the importance of students making connections with the content being covered. If students are able to engage in scientific practices that help create meaning, not only will they be better equipped to write and defend arguments about this content, but they will also develop a more thorough and lasting understanding of the science content.

Another theme of the literature was the combination of inquiry and argumentative writing when students use evidence to develop and defend arguments. Kelly and Bazerman (2003) indicated that in order for this instructional strategy to be successful, students needed to be explicitly taught the conventions of scientific discourse. Furthermore, Cheuk (2016) identified four mechanisms to support argumentation in the science classroom, which included facility with the components of an argument and scaffolds. This research reached the same conclusions. Students performed better on writing tasks when they were provided with a scaffold that clearly outlined the claim, evidence, and reasoning for students to organize into a coherent argument.

They would likely perform even better if additional support structures were implemented, based on identified areas of student need. Students come into the classroom with varying English fluency and writing ability levels, and when developing strategies for teaching argumentative writing in the science curriculum, the vast diversity of learners in any classroom needs to be taken into consideration and should receive adequate support to meet these learning expectations.

González-Howard, McNeill, and Ruttan (2015) described strategies from a sheltered English immersion classroom, such as simplifying claims and discussing meanings of words or phrases, that can be further utilized to support students in engaging in this type of argumentative writing. This research indicated that students need additional support with developing claims and evidence, and similar “think-aloud” discussion strategies used for English learners can be adapted for whole-class instruction in order to break down complex components of lab activities. Even though the strategies described by González-Howard, McNeill, and Ruttan (2015) were intended to support students’ ability to make a claim, they can be adapted for argumentation sessions and lab reports to support students’ use of claim, evidence, and reasoning, as students gain familiarity with this form of scientific discourse.

Vygotsky (1978) emphasized the critical importance of collaboration in the learning process, and this study reached the same conclusions. The results of this research indicated a clear need for consistent, thorough peer feedback in the writing process. In this model of instruction, feedback comes from two areas: the argumentation session and the peer editing process. This research indicated that both of these areas are necessary in this model, in part because students can check their own work by hearing and seeing other students’ ideas and because they can receive feedback on their own work. In particular, students need this feedback on all areas of argumentative writing: claim, evidence, and reasoning. Student responses also indicated the need for a more knowledgeable other that can provide this feedback. Differentiating this process for all students will also mean developing strategies for providing this feedback to more confident scientific writers. These adaptations are lacking in the literature, and this can be a direction for further research.

This research heavily drew upon the description of the ADI model in the literature and simplified it for usage in the middle school science classroom. Sampson, et al. (2013) and Grooms, Enderle, and Sampson (2015) both indicated a need to determine "nonnegotiable" aspects of the ADI model. This research concluded that the following aspects should be considered non-negotiable: student-collected data, comprehensive argumentation sessions, peer feedback on lab reports, and revision of writing. In addition, this research suggests that this instructional sequence should include comprehensive expectations for peer feedback in order to make it useful for all students. Since the body of literature on the relationship between NGSS, inquiry, and argumentative writing is still developing, this research can provide insight on potential methods of teaching argumentative writing using scientific inquiry, with a unique perspective on the needs of sixth-grade students.

Limitations/Gaps in the Research

First and foremost, a constraint in this research was the expertise of the instructor. The NGSS have only recently been developed, and guidelines for teaching according to these standards are still under development. While the instructor has received some NGSS training, she has not received professional development focused squarely on the SEPs. Furthermore, certain NGSS strategies used within the context of this research are fairly new to the instructor, and fairly new to the field of education, as a whole. Had the teacher had the time and experience to practice these strategies for a longer period of time preceding this research, different results may have been observed.

In addition, the sample size of this research was limited to only 73 sixth-grade students, which is a very small sample size and a very small age range. Since the sixth-grade teachers are expected to teach certain content standards within a set amount of time, the timing of lab activities proved to be an issue. Labs could not take more than a few days of instructional time, and needed to be relevant to the content standards at hand. At the time of this study, students were learning about human body systems. Different results may have been observed if these lab activities had been implemented for other topics in life science, or even for earth and/or physical science topics. Students only engaged in these lab activities throughout the course of this research, but if this lab sequence had been implemented with fidelity over the course of the school year, results may have varied.

Another limiting factor was the reliability of Assessments 1.1 and 1.2, which measured students' ability to identify, critique, and compare and critique evidence in an argument, and were obtained from Knight, et al. (2013). Through a Cronbach's test, these assessments were determined to have an overall reliability of 0.79 (*Classical and Rasch Analysis of: Relevant Supporting Evidence*, p. 17). Ideally, an assessment with a greater reliability coefficient would have been used, but since student engagement in argumentative reading and writing in science classes is a relatively new trend, very few established assessments are available.

Implications for Future Research

This study attempted to determine how engaging in argumentative writing practice influenced students' ability to engage in evidence-based argument in the science classroom. As the NGSS continue their widespread implementation nationwide, classroom teachers need to determine how to best support literacy in the science curriculum in a way that matches their own teaching styles, their student populations, and their school and district cultures. The ADI model is a starting place, but does not cleanly fit the needs of all grade levels or science content areas. Restriction of time and materials can also severely impact a teacher's ability to implement this curriculum model on a regular basis. This research shows that, even when simplified from the original ADI model, similar classroom activities have the potential to help students develop the skills they need to engage in argument through evidence.

Even so, further research needs to be conducted on the specific aspects of this model that contribute to the growth of these skills. In particular, this method of instruction allowed students to more effectively identify, critique, and compare and critique the quality of evidence used in an argument. Analysis of this research concluded that this improvement may have been due to the consistent incorporation of evidence into the inquiry-based writing exercises in question, but since this may not be a possibility for all classrooms or science content areas, further research needs to be done on the impact of analyzing data that is not student-collected. Furthermore, although students improved in their ability to construct clear, complete scientific claims, increases in the ability to utilize evidence and reasoning to support these claims were not statistically significant. This indicates a need for the development of argumentation sessions that specifically support students' ability to utilize these components of scientific arguments.

Although models can be helpful, they need to be adjusted to the needs of the class in question. Following a specified sequence of instruction may be helpful for some populations of students, but not others, so when developing or adjusting curriculum of any kind, teachers need to be responsive to the needs of their specific students. The results of this research demonstrate a clear need for research on differentiation strategies to support scientific argumentative writing for all students. Argumentative writing is a skill that all students, regardless of language ability or fluency, will need to develop, and teachers need to figure out strategies for how to scaffold it for all language levels. For example, González-Howard, McNeill, and Ruttan (2015) developed a series of strategies to support students in a sheltered English immersion classroom to construct scientific claims. Similar strategies are needed to support all students with constructing not only claims, but also evidence and reasoning to support those claims. Furthermore, strategies are needed to support more proficient writers who may not benefit from the feedback of their peers.

Norris and Phillips (2003) claim that fundamental literacy, "reading and writing when the content is science," (p. 224) is essential for successful writing in the science curriculum. The practice of writing needs to be supported in all content areas in order for students to possess these skills. However, according to a 2009 study by Kiuhara et al., science teachers, in general, do not expect students to do much writing, provide little explicit writing instruction, and do not view writing instruction as their responsibility because they see it as less important than do teachers in other content areas. There is a clear need for further research on what would empower teachers to support literacy in their content areas, and what school and district structures may be needed for them to be able to do so.

The ADI model in the science curriculum encourages the use of empirical data as evidence in student reports. Students' ability to utilize this data as evidence for an argument is applicable across content areas. Students will not always have numbers in front of them, but when writing in other content areas, they may use quotes, observations, or research as the basis for forming arguments. The research literature, overall, yielded very little information about classroom strategies that could support this practice in content areas other than science. This suggests a need for further research on argumentative writing teaching strategies and exercises in other content areas. Furthermore, further research is needed on possible connections between argumentative writing instruction in the science curriculum and the language arts curriculum, and how teachers can potentially collaborate and/or design curriculum to support this practice among the different content areas.

At the present time, there is currently no clear idea of what NGSS assessments will look like, and how students will be expected to demonstrate the use of evidence to construct arguments. As these assessments roll out, and school officials and teachers gain a clearer understanding of these performance goals, they will also be able to more clearly construct the science curriculum to better meet these learning goals. At that time, further research will be needed to determine specific methods of scaffolding classroom instruction and written exercises and tasks to meet these goals. No matter what the NGSS assessments look like, the fact remains that argumentative writing is a critical skill for students to learn. Ideally, the looming specter of NGSS will light a fire that sparks further research leading to knowledge of how to support this practice in the science classroom and beyond.

Overall Significance of the Study

The NGSS establish inquiry as an integral part of content standards. Therefore, these standards are pushing the U.S. science curriculum toward an increase in inquiry-based teaching and learning, and placing more emphasis on scientific literacy and writing. An essential science and engineering practice, as identified by the NGSS, is arguing through evidence. This is often taught through the student use of claim, evidence, and reasoning to analyze and interpret the significance of a set of data. This study draws upon the Argument-Driven-Inquiry model, modifying it in a way to make it more usable in light of varying student populations, department expectations, time limitations, and grade levels. Conclusions from this research demonstrate specific ways that ADI-based instruction can be helpful and makes recommendations for effective argumentative writing instruction in general. Since argumentation is such an essential part of scientific data analysis, it is necessary for science teachers to find ways to effectively support this practice in their classrooms, especially in light of NGSS. The goal of NGSS is to build scientifically literate human beings who both appreciate the role of science in the world and are able to comprehend and interpret scientific information with a critical eye. Continued usage of writing as a means of science content instruction will help teachers build these skills in their students, and this study demonstrates specific suggestions for supporting these practices within the classroom.

About the Author

Gabriela Mastro has been a science teacher at a public school for two years. Preceding this, she was an eager science student who loved writing lab reports and found a talent for expressing scientific information through writing. As she continues to learn and grow as a professional educator, she seeks to build a culture within her classroom that makes science accessible for all students, and to create a passion for science within those students, just like her own teachers have done for her throughout her education. Her goal is for her students to eventually help dispel the myth that "scientists can't write," and to use evidence-based science to create change in their communities.

References

American Psychological Association. (2010). *Publication manual of the American Psychological Association.* Washington, DC: American Psychological Association.

Bar, V., Brosh, Y., & Sneider, C. (2016). Weight, Mass, and Gravity: Threshold Concepts in Learning Science. *Science Educator*, *25*(1), 22-34.

Bell, R. L., Smetana, L., & Binns, I. (2005). SIMPLIFYING Inquiry INSTRUCTION. *Science Teacher*, *72*(7), 30-33.

Bowman, L. L., Jr., & Govett, A. L. (2015). Becoming the Change: A Critical Evaluation of the Changing Face of Life Science, as Reflected in the NGSS. *Science Educator, 24*(1), 51-61.

Cavagnetto, A. R. (2010). Argument to foster scientific literacy: A review of argument interventions in K-12 science contexts. *Review of Educational Research*, *80*(3), 336-371. doi:10.3102/0034654310376953

Cheuk, T. (2016). Discourse Practices in the New Standards: The Role of Argumentation in Common Core-Era Next Generation Science Standards Classrooms for English Language Learners. *Electronic Journal of Science Education, 20*(3), 92.

Classical and Rasch Analysis of: Relevant Supporting Evidence. (n.d.) Retrieved from: http://sciencearguments.weebly.com/uploads/2/6/4/3/26438648/techreport_rse.pdf

Demirel, M., & Caymaz, B. (2015). Prospective Science and Primary School Teachers' Self-efficacy Beliefs in Scientific Literacy. *Procedia - Social and Behavioral Sciences, 191*, 1903-1908. doi:10.1016/j.sbspro.2015.04.500

Erduran, S., & Jiménez-Aleixandre, M. P. (2007). Contemporary Trends and Issues in Science Education : Argumentation in Science Education : Perspectives from Classroom-Based Research. Dordrecht, NL: Springer. Retrieved from http://www.ebrary.com

Farris, P. J., Werderich, D., & Haling, L. (2016). Facilitating Scientific Literacy: Strategies to Infuse Reading and Writing. *Illinois Reading Council Journal, 44*(4), 3-11.

Fives, H., Huebner, W., Birnbaum, A. S., & Nicolich, M. (2014). Developing a Measure of Scientific Literacy for Middle School Students. *Science Education, 98*(4), 549-580. doi:10.1002/sce.21115

González-Howard, M., McNeill, K. L., & Ruttan, N. (2015). "What's our three-word claim?": Supporting English language learning students' engagement in scientific argumentation. *Science Scope, 38*(9), 10.

Grooms, J., Enderle, P., & Sampson, V. (2015). Coordinating Scientific Argumentation and the Next Generation Science Standards through Argument Driven Inquiry. *Science Educator, 24*(1), 45.

Kiuhara, S. A., Graham, S., & Hawken, L. S. (2009). Teaching writing to high school students: A national survey. *Journal of Educational Psychology, 101*(1), 136-160. doi:10.1037/a0013097

Knight, A. M., McNeill, K. L., Corrigan, S., & Barber, J. (2013, April). *Student assessments for reading and writing scientific arguments.* Paper presented at the annual meeting of the American Educational Research Association, San Francisco.

MacDonald, C. (2012). Understanding participatory action research: A qualitative research methodology option. *Canadian Journal of Action Research*, 13(2), 34-50.

National Committee on Excellence in Education. (1983). *A nation at risk: The imperative for educational Reform—A report to the nation and the secretary of education*. Washington, D.C.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, D..C.: National Academies Press.

National Research Council. (1996). *National Science Education Standards*. Washington, D.C.: National Academies Press. doi: 10.17226/4962.

National Research Council (2013). “Appendix K: Model Course Mapping in Middle and High School for the Next Generation Science Standards.” *Next Generation Science Standards: For States, By States.* Washington, D.C.: National Academies Press.

NGSS Lead States. (2013). Appendix M – Connections to the Common Core State Standards for Literacy in Science and Technical Subjects. *Next Generation Science Standards: For States, By States* (pp. 159). Washington, D.C.: The National Academies Press.

Norris, S.P. & Phillips, L.M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, 87(2), 224-240. doi:10.10002/sce.10066

Opportunity Equation: Transforming Mathematics and Science Education for Citizenship and the Global Economy (2009). Carnegie Corporation of New York.

Otfinowski, R., & Silva-Opps, M. (2015). Writing toward a scientific identity: Shifting from prescriptive to reflective writing in undergraduate biology. *Journal of College Science Teaching, 45*(2)

Patten, M. (2012). *Understanding Research Methods: An Overview of the Essentials* (8th ed.). Glendale, CA: Pyrczak Publishing.

Sampson, V., Grooms, J., & Walker, J. (2011). Argument-driven inquiry as a way to help students learn how to participate in scientific argumentation and craft written arguments: An exploratory study. Science Education, 95(2), 217 – 257.

Sampson, V., Enderle, P., Grooms, J., & Witte, S. (2013). Writing to Learn by Learning to Write During the School Science Laboratory: Helping Middle and High School Students Develop Argumentative Writing Skills as They Learn Core Ideas. *Science Education, 97*(5), 643-670. doi:10.1002/sce.21069

Step Up To Writing [Brochure]. (n.d.) N.P.: Voyager Sopris Learning. Retrieved from: http://www.voyagersopris.com/docs/librariesprovider7/literacy-solutions/step-up-to-writing/sutw-overview.pdf?sfvrsn=4

Tomas, L., & Ritchie, S. (2015). The Challenge of Evaluating Students' Scientific Literacy in a Writing-to-Learn Context. *Research in Science Education, 45*(1), 41-58. doi:10.1007/s11165-014-9412-3

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wheeler-Toppen, J. (2012) *How Do You Know That? Helping Students Write About Claims and Evidence* [PowerPoint Slides]. NSTA Web Seminars, 33. Retrieved from: https://learningcenter.nsta.org/products/symposia_seminars/NSTA/files/HowDoYouKnowThat--HelpingStudentsWriteAboutClaimsandEvidence_12-12-2012.pdf

Wilcox, J., Kruse, J. W., & Clough, M. P. (2015). Teaching Science Through Inquiry. *Science Teacher, 82*(6), 62-67.

Wissehr, C., Concannon, J., & Barrow, L. H. (2011). Looking back at the Sputnik era and its impact on science education. *School Science & Mathematics*, *111*(7), 368-375. doi:10.1111/j.1949-8594.2011.00099.x

Appendix A: Assessment 1.1

This assessment was obtained and modified from Knight, et al. (2013).

Mrs. Johnson asks her students to write an argument about the following question:

What is related to how much energy an earthquake releases?

Terrance used the data table below to write his argument:

Number of Earthquakes Per Year	**Energy Released from Earthquake** (Size of Earthquake)
1	Very Large
15	Large
134	Medium
1,319	Small
13,000	Very Small

Terrance's Argument:

(S1) = Sentence 1, (S2) = Sentence 2, (S3) = Sentence 3

(S1) *There tend to be fewer earthquakes that release lots of energy.* ***(S2)*** *Each year there are about 13,000 earthquakes that release a very small amount of energy, but only one earthquake that releases a very large amount of energy.* ***(S3)*** *This means that fewer earthquakes are likely to occur when lots of energy is released.*

Q1. Terrance is thinking of adding more evidence to his argument. Which piece of evidence best supports his claim? **(Circle your answer.)**

a) The 1920 Haiyuan Earthquake released a very large amount of energy and was the largest earthquake this century.

b) There are about 130,000 earthquakes that release an extremely small amount of energy every year.

c) There are about 130,000 earthquakes that release a very large amount of energy every year.

d) While there are about 500,000 earthquakes measured each year, only about 100,000 of them are in the United States.

Q2. Terrance claims that there tend to be fewer earthquakes that release lots of energy. He wants to add the following piece of evidence:

The NEIC now locates about 50 earthquakes each day, or about 20,000 a year.

Should Terrance use this piece of evidence in his argument? **(Circle your answer.)**

a) No because it does not support Terrance's claim.

b) No because it supports the opposite of Terrance's claim.

c) Yes because it supports a different claim than Terrance's.

d) Yes because it supports Terrance's claim.

Dina is also in Mrs. Johnson's class. Mrs. Johnson asked Terrance and Dina to compare arguments to see who used stronger evidence.

Terrance's Argument:

There tend to be fewer earthquakes that release lots of energy. Each year there are about 13,000 earthquakes that release a very small amount of energy, but only one earthquake that releases a very large amount of energy. This means that fewer earthquakes are likely to occur when lots of energy is released.

Dina's Argument:

There tend to be fewer earthquakes that release lots of energy. In 2011 there were 2,276 earthquakes that released a small amount of energy, but there are usually about 1,319 earthquakes that release this amount of energy. Therefore, more earthquakes will probably happen when less energy is released.

Q3. Which student, Terrance or Dina, better supports his or her argument? Why?

Appendix B: Assessment 1.2

This assessment was obtained and modified from Knight, et al. (2013).

Mrs. Elton asks her students to write an argument about the following question:

What is related to the thickness of magma?

Shawn used the data table below to write his argument:

Name of Volcano	**Air Temperature** when volcano erupted	**Thickness of Magma**	**Estimated Temperature of Magma**
Fernandina	14°C	Runny	1,000-1,200°C
Ojos del Salado	31°C	Sticky	800-1,000°C
Picabo	22°C	Very Sticky	650-800°C

Shawn's Argument:

(S1) = Sentence 1, (S2) = Sentence 2, (S3) = Sentence 3

(S1) *Volcanoes that have very hot magma tend to have runny magma.* ***(S2)*** *The Fernandina Volcano has some of the hottest magma scientists know of (more than 1,000°C). and it also has some of the runniest magma.* ***(S3)*** *The Fernandina Volcano is a good example because it is like other volcanoes that have high temperature magma that is runny.*

Q1. Shawn is thinking of adding more evidence to his argument. Which piece of evidence best supports his claim? **(Circle your answer.)**

e) Magma of the Pisagh Volcano in North America is thought to have reached temperatures exceeding 1,000°C.

f) Some volcanoes in the Andes can create magma with temperatures as high as 1,125°C and still have sticky magma.

g) The volcano called Sturtsey in Iceland recently produced magma with average temperatures over 1,200 °C and had runny magma.

h) Some of the stickiest magma so far came from the Cleveland Volcano in Alaska, North America.

Q2. Shawn claims that volcanoes produce very hot magma tend to have runny magma. He wants to add the following piece of evidence to his argument.

> *Volcanoes like Pirongia in New Zealand had very hot magma that was well over 1,100* °C *and was categorized as being very sticky*.

Should Shawn use this piece of evidence in his argument? **(Circle your answer.)**

a) No because it does not support Shawn's claim.

b) No because it supports the opposite of Shawn's claim.

c) Yes because it supports a different claim than Shawn's.

d) Yes because it supports Shawn's claim.

Alison is also in Mrs. Elton's class. Mrs. Elton asked Shawn and Alison to compare arguments to see who used stronger evidence.

Shawn's Argument:

Volcanoes that produce very hot magma tend to have runny magma. The Fernandina Volcano has some of the hottest magma scientists know of (more than 1,000°C*) and it also has some of the runniest magma. The Fernandina volcano is a good example because it is like many other volcanoes that have high temperature magma that is runny.*

Alison's Argument:

Volcanoes that produce very hot magma tend to have runny magma. The Picabo volcano in North America has very cool magma (less than 800°C*), but it was still thin and runny compared to magma from other volcanoes. The Picabo Volcano magma is a good example because even when it is cool, it can still be thin and runny.*

Q3. Which student, Shawn or Alison, better supports his or her argument? Why?

Appendix C: Assessment 2.1

This assessment was obtained and modified from Knight, et al. (2013).

Joe wonders what is related to the strength of an earthquake.

Dr. Schmidt visited Joe's class and explained that she studies earthquakes that affect islands. They learn that right now she is studying the Haiti 2010 earthquake, and that the city called Port-au-Prince is where the strength was the greatest.

Joe learns that:

- Some earthquakes start deeper inside the Earth than others.
- Some rocks types shake more easily than others.
- Earthquakes start underneath the Earth's surface and that is where they are the strongest.
- The depth where an earthquake started and the rock type usually affect the strength of an earthquake.

Earthquake	**Strength** at Earth's surface (MMI Scale: 0-12) 0 = low, 12 = high	**Depth** of Earth's surface where earthquake started	**Rock Type**	**Air Temperature** when earthquake started
A	12	20 km	Soft	22°C
B	10	115 km	Soft	31°C
C	8	222 km	Soft	14°C
D	7	373 km	Hard	26°C
E	5	500 km	Very Hard	68°C

Joe also found the table below:

Joe and his classmates need your help. Students in his class have different ideas about what is related to the strength of an earthquake.

Using the information Joe learned about earthquakes, write an argument to Joe's class that answers the question:

What is related to the strength of earthquakes?

When you are writing your argument keep in mind:
1) Justifying your claim with evidence and reasoning and
2) Convincing Joe and his classmates that your claim is stronger than other claims

Appendix D: Assessment 2.2

This assessment was obtained and modified from Knight, et al. (2013).

Aisha wonders what is related to the power of a volcano's eruption.

On a field trip to a science museum, Dr. Martin tells Aisha that he studies large volcanoes from around the world. Aisha learns that the largest volcano on Earth is Mauna Loa, and that it is the newest of the volcanoes in the Hawaiian Islands.

Aisha learns that:

- The magma from some volcanoes has more gas bubbles and is thicker than magma in other volcanoes.
- The power of an eruption is related to the amount of pressure built up by the magma inside the volcano.
- The thickness of the magma and the number of gas bubbles in the magma affect how explosive the volcanic eruption is.

Aisha also found the table below:

Volcano	**Power of Eruption** VEI Scale: 0 to 8 (0 = low, 8 = high)	**Average Surface Temperature** at Eruption Site	**Thickness of Magma**	**Number of Gas Bubbles in Magma**
A	6	6°C	Sticky	Many
B	5	24°C	Sticky	Many
C	3	18°C	Sticky	Many
D	2	31°C	Runny	Few
E	1	12°C	Runny	Few

Aisha and her classmates need your help. Students in his class have different ideas about what is related to the power of a volcano's eruption.

Using the information Aisha learned about volcanoes, write an argument to Aisha's class that answers the question:

What is related to the power of a volcano's eruption?

When you are writing your argument keep in mind:

1) Justifying your claim with evidence and reasoning and
2) Convincing Aisha and her classmates that your claim is stronger than other claims

Appendix E: Assessment 3.1 – Ruler Drop Lab

Essential Question: Does a person's age affect their reaction time?

Data Collection:

1. Rest your elbow on a table and extend your arm as shown.
2. Have a team member hold a meter stick in the air, with the 0-cm line between the thumb and finger of your extended hand.
3. The team member will unexpectedly drop the meter stick. Catch it as quickly as possible.
4. Observe the position of your thumb and index finger in centimeters (cm) after catching the ruler. Record this number on the data table.
5. Repeat Steps 2-4 five times for both you and your partner.

Data Table #1 (YOUR DATA): (Your age: ________)

Trial #	1	2	3	4	5	Avg.
Distance (cm)						

Data Table #2 (Averages):

Age Range	11 and younger	12-24	25 and older
Average Distance (cm)			

Ruler Drop Lab - Analysis
Develop an argument to answer the EQ:

According to the data you have collected, does age affect a person's reaction time?

1. Develop an argument in the space below (bullet points okay):

Claim (Answer to the question)	
Evidence (Numbers from data table that support your answer)	

Reasoning (Explanation of why those numbers support your answer)	

2. On the following page, write a paragraph that answers the above question. Be sure to include:

- Claim
- Evidence
- Reasoning
- Topic and conclusion sentences, academic vocabulary

Appendix F: Assessment 3.2 – Sweaty Science!

Essential Question: How does exercise affect heart rate and respiratory rate?

Heart Rate:
1. Perform each of the following activities for 60 seconds each.
2. After 60 seconds, stop, find your pulse, and count how many times your heart beats for 15 seconds.
3. Multiply this number by 4 to find your heart rate in **beats per minute (bpm)**.

Activity	**Sitting**	**Running in Place**	**Jumping Jacks**	**Chair Steps**
Heartbeats (15 s)				
Heart Rate (60 s - beats per minute)				

Respiratory Rate:
1. Perform each of the following activities for 60 seconds each.
2. After 60 seconds, stop. Count how many times you breathe (inhale) in 15 seconds. **BREATHE NORMALLY.**
3. Multiply this number by 4 to find your respiratory rate in **breaths per minute**.

Activity	**Sitting**	**Running in Place**	**Jumping Jacks**	**Chair Steps**
Breaths (15 s)				
Respiratory Rate (60 s - breaths per minute)				

Develop an argument to answer the EQ:

How does exercise affect heart rate and respiratory rate?

1. Develop an argument in the space below (bullet points okay):

Claim (Answer to the question)	
Evidence (Numbers from data table that support your answer)	

Reasoning (Explanation of why those numbers support your answer)	

2. On the following page, write a paragraph that answers the above question. Be sure to include:

- Claim (Topic sentence)
- Evidence
- Reasoning
- Conclusion Sentence
- Science facts, academic vocabulary, careful spelling, grammar, and punctuation

Appendix G: Rubric for Assessments 1.1 and 1.2

Rubric and both assessments were obtained from Knight, et al. (2013).

Multiple-Choice:

Question	Assessment 1.1 (Appendix A)	Assessment 1.2 (Appendix B)
1	B	C
2	A	B

Free-Response

Score	Description
3 Correct choice; Compare and Critique	Student makes a correct choice and critiques the quality of the evidence by comparing the evidence used in both arguments (relevant-supporting, relevant-contradictory, or irrelevant)
2 Correct choice; Critique	Student makes a correct choice and critiques the quality of the evidence used in one of the arguments (relevant-supporting, relevant-contradictory, or irrelevant)
1 Correct Choice	Student makes a correct choice and writes that one argument provides stronger evidence. However, the identified reason is wrong. OR Student does not identify any reason even though s/he makes a correct choice
0 No Choice; Incorrect Choice	Student does not make any choice OR Student makes a wrong choice

Appendix H: Rubric for Assessments 2.1, 2.2, 3.1, and 3.1

Rubric was obtained and modified from Knight, et al. (2013) and Wheeler-Toppen (2012, p. 33)

Score	**Claim**	**Evidence**	**Reasoning**
3	Makes an accurate and complete claim.	Student limits all of the SPECIFIC empirical evidence to that which is relevant to the science in the claim and supports the relationship in the claim.	Provides reasoning that links the evidence to the claim. Includes appropriate and sufficient scientific principles to explain why the evidence supports the claim.
2	Makes an accurate, but incomplete claim.	Student uses empirical evidence that supports and is relevant to the relationship in the claim. OR Student limits evidence to that which is relevant and supportive of claim, BUT does not cite specific numbers or observations.	Provides appropriate, but incomplete reasoning. (Not all evidence is accounted for.)
1	Makes an inaccurate claim. OR Makes a claim that fails to take a clear position on the question.	Student provides a mixture of relevant-supporting empirical evidence as well as irrelevant and/or non-supporting data to support the relationship in the claim. OR Student only provides some of the necessary relevant-supporting empirical evidence to support the relationship for part of the claim.	Provides inappropriate reasoning that fails to link evidence to claim. OR Reasoning simply re-states evidence.
0	Does not make a claim.	Student provides only irrelevant or non-supporting data for his/her claim. OR Data is not mentioned.	Does not provide reasoning.

Appendix I: Peer-Edit Checklist

1. Claim: Does the author have a clear, focused claim that says what the paragraph will be about?
   - Yes
   - Claim is unclear - "I don't know" or "maybe."
   - No, there is no claim.

2. Evidence: Does the author provide at least **two (2) pieces of evidence** (specific numbers or observations) that help to prove or support the claim?
   - Yes
   - Only one piece of evidence (number or observation) is provided
   - No, there is no evidence.

3. Reasoning: Does the author clearly and thoroughly explain **how and/or why the evidence (numbers) support the claim**?
   - Yes
   - Reasoning is somewhat clear, but needs some more explanation
   - No, there is no reasoning.

Underline claim, circle evidence, box reasoning, and correct all spelling, grammar, and/or punctuation errors that you find.

Likes:	
Wonders:	