Science and Mathematics Education Centre

The Evolution of 7th Graders Scientific Explanations in Project-Based Classrooms

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This thesis is presented for the Degree of
Doctor of Philosophy
of
Curtin University

December 2014

Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief, this thesis contains no material previously published by any person except where due acknowledgement has been made.

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ABSTRACT

This thesis documents the process of 58, 7th grade students constructing one explanation, through multiple iterations, as new evidence was obtained. Students wrote four iterations of one explanation during a semester project where they investigated the water quality of a local stream; students expanded and revised this explanation, termed "evolving explanation" to reflect this process, over the course of six weeks as they collected more data from various water quality measures – pH, temperature, conductivity and dissolved oxygen. Utilizing a time series research design, the four iterations were collected and analyzed for each student. Teacher feedback from the second and third iterations was also collected. The study also examined the support a teacher provided to assist students as their explanations progressed from less to more sophisticated. The challenges that students faced are also documented. Overall, this study is concerned with supporting students to develop integrated understanding of water quality and human impact on water - through building a more sophisticated explanation over time.

The study is designed to add to the growing body of research on how students learn and how to teach more effectively so that future generations will be able to explain various phenomena, have tools to continue to develop their understanding, and use knowledge to solve problems. The study took place in classrooms with a project-based curriculum that utilized 3-Dimensional Learning: the blending of scientific ideas, scientific practices, and crosscutting concepts as the instructional approach, to assist students to make sense of a complex phenomenon and better understand nature of science, particularly that scientific knowledge is open to revision. One practice is constructing evidence-based explanations to make sense of phenomenon.

Research supports the value of developing curricula with an iterative rather than a sequential focus where ideas build over time. The curriculum in this study utilized this iterative focus. A number of studies explored how students created different explanations based on new phenomena. In some studies, students gained experience in writing several different explanations. Concepts were revisited with different data. An iterative approach, however, is taken one step further in this study. Students used core ideas and explained causal relationships by constructing and expanding one explanation through multiple iterations. Students both revised and expanded one explanation as more evidence was collected related to the same phenomenon. This research explored whether or not each iteration helped students gain more knowledge of the science ideas for water quality, thereby assisting them to organize their knowledge around the core concepts to develop a more integrated understanding.

When investigating more complex phenomena and collecting data over time, evidence initially gathered logically led to one claim, but needed to be adjusted later after obtaining new evidence that no longer supported the initial claim. As such, the claim portion of scientific explanations, generally seen as the part most accessible to students, became a challenge for some students under this more complex circumstance where claims were not so clear-cut and where students needed to rethink their claims that were once fully supported by the evidence.

For data analyses a comprehensive concept map followed by a rubric of the science ideas were developed. Qualitative measures to look for commonalities and differences among the data were used. Various patterns emerged, particularly related to claims. Statistical analyses that included ANOVA using a repeated measure design, crosswise comparisons, and regression analyses were also conducted. These analyses were used to track the development that students made through the four iterations of the explanation related to building science ideas, to determine whether or not students connected science ideas to evidence, and what was most predictive of the claims that students generated based on two, three, or four pieces of evidence.

Based on the findings, I argue that using an evolving scientific explanation within a 3-dimensional learning environment facilitated students towards development of integrated understanding of the science concepts explored. Students worked to develop knowledge structures across time that allowed them to apply those understandings to explain phenomena and be prepared for future learning. Research suggests that reasoning, connecting science understanding with evidence, is the most difficult for students when explaining phenomena. Findings from this study shed important light on how to support students to become better at reasoning thereby connecting science understandings with evidence.

DEDICATION

To Joe: the love of my life and my mentor, my closest professional colleague and dearest friend, who pushes my thinking and provides me with support, ever so thoughtful and always with grace.

To my students: the love affair started the minute I walked into the classroom. Thank you for allowing me to be a part of your journey and for being a rich part of mine.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Professor David Treagust for his support and encouragement during this project. I would also like to thank Dr Chandrasegaran, who assisted with the statistical analyses. Special thanks to Dr Namsoo Shin, who helped me early on with data analyses and also helped me to interpret my results. Thanks to Chris Gleason and Martha Friedlander for their help scoring student explanations to establish validity. Joe Krajcik was particularly instrumental in all aspects of the thesis from start to finish, and I would like to thank him. Thanks to Petrina Beeton for the final formatting of the thesis. Greenhills School, where I have both the pleasure and honor to teach, provided financial support, and I am truly grateful for their commitment to my professional development. I would like to thank my students for participating in my study and their families for allowing me to collect and analyze data from their science classes; I greatly appreciated and am honored by their trust. Finally, I am thankful to my family—my husband Joe, my children Michael, Paul, and Ellen, their spouses Erin, Carla, and Ryan, and my wonderful grandchildren Juliet, Elise, Maggie, and Amaya. Learning is a lifelong pursuit and I am thankful that those closest to me are learners!

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Introduction to the Thesis

1.1 Introduction and Overview of the Study

Helping students become scientifically literate is a goal of K-12 education. Scientifically literate citizens can make sense of the natural world and use their understandings to explain phenomena, solve problems, and make decisions related to societal problems (National Research Council, 2012; National Science Education Standards 1996). If schools are to assist students towards scientific literacy they need to provide students with experiences that foster the development of useable knowledge structures, or integrated understanding, like those of experts. What do these experiences look like and how can teachers' best support students to develop useable knowledge?

The aim of this thesis is to explore students' development towards integrated understanding and the learning environment and support that is provided by a teacher. In this knowledge-centered environment, students work to explain a complex phenomenon, the health of a stream for local freshwater organisms, where they construct an evidence-based scientific explanation over a period of weeks as more data are collected. The underlying theory for the work in this thesis is based on social constructivism (Vygotsky, 1986) where students actively engage with phenomena and collaborate with each other and the teacher to make sense of ideas by constructing integrated understanding.

Two major goals of science education are to assist students to be able to explain various phenomena and to solve problems. Scientists often construct evidence-based explanations for phenomena. Students should also engage in the same activities of scientists. With new insights from research over the past two decades into how students learn and how to more effectively teach science, various documents have been published that use this growing body of research to assist teachers and curriculum designers. To best prepare the next generations of learners to deeply understand and explain scientific phenomena and to have the tools to use that knowledge to respond to challenging current and future problems that face our societies and our planet, a new instructional approach has been proposed in the *Framework for K-12 Science Education* (NRC, 2012). This new approach, referred to as 3-Dimensional Learning, the blending of scientific and engineering practices, crosscutting concepts, and crosscutting disciplinary core ideas, is the methodology for science instruction used in the study reported in this thesis. While few examples illustrative of 3-Dimensional Learning exist, the learning context in this study provides an example of 3-dimenational learning. It investigated student learning within a project-based curriculum that blends the practice of constructing scientific explanations, the crosscutting concept of cause and effect, and disciplinary core ideas related to *Earth and Human Activity* and *Ecosystems: Interactions, Energy, and Dynamics* specifically related to water quality.

This chapter provides an overview and rationale for the study. It will include a brief background of the literature in the area that is expanded upon in more detail in Chapter 2. The research questions for the study are included as well as an overview of the methodology of the study. The significance of the study to the field of science education is included. The chapter concludes with a synopsis of the sequencing of the document with a brief summary of each chapter.

1.2 Rationale of the Study

This study stems from the growing body of research on how students learn and how to teach more effectively so that future generations will be able to explain various phenomena and have tools to continue to develop their understanding and use their knowledge to solve problems that they encounter. The study is designed to add to this body of research within a project-based curriculum that utilizes 3-Dimensional Learning (National Research Council 2012) as the methodology for science instruction. One practice - constructing evidence-based explanations - is emphasized in many of the major science education documents (Michaels, Shouse, & Schweingruber, 2008; American Association for the Advancement of Science 2008; National Research Council 2007; Bransford, Brown & Cocking, 2000); indeed, a major goal of science and the work of scientists is to construct evidence-based explanations about scientific phenomena. When students are supported in developing explanations, learning is fostered (McNeill, Lizotte, Krajcik, & Marx, 2006). Osborne (2014) argues that scientific practices (like constructing explanations) place cognitive demands on students that improve the quality of their learning but argues that currently these demands are rarely part of students' experiences (Obsorne, 2014). Engaging students in regularly constructing scientific explanations as well as exploring how to help teachers to assist their students in this important scientific practice is clearly of importance to the research and teaching communities.

Research also supports the value of developing curricula with an iterative rather than sequential focus (Bransford, Brown & Cocking, 2000; Fortus & Krajcik, 2011; NRC, 2012) where ideas build over time so that they become richer and more sophisticated. The curriculum investigated in this study utilizes this iterative focus. A number of studies that have explored how students create different explanations based on new phenomena are summarized in Cavagnetto (2010). In some of these studies, students gained experience in writing several different explanations throughout the curriculum. Concepts were revisited with different data. However, the idea of an iterative approach is taken one step further in this study. Students develop one explanation, over a period of time, as new evidence is gathered in an authentic context. They expand and revise this explanation as more data are obtained that provides them with a more comprehensive picture of the phenomenon. Consequently, curriculum utilized in this study explores an authentic, more complex phenomenon, namely the water quality of a stream; if the stream is healthy for freshwater organisms and human impact on the stream, where data are collected over a several week period.

Within a 3-Dimensional Learning environment students use core ideas and explain causal relationships constructing one scientific explanation through multiple iterations. Students both revise and expand one explanation, termed an evolving explanation, as more sources of evidence are collected related to the same phenomenon. Another goal of science education is to assist students to understand nature of science (Nature of Science Matrix, NGSS 2013, Appendix H). One component of Nature of Science stresses that, in light of new evidence, scientific knowledge is open to revision (p. 97). The research in this study seeks to explore if each iteration helps students delve deeper into science ideas, thereby assisting them to organize their knowledge around core concepts (Chi, 2011; Hmelo-Silver & Pfeffer, 2004; Rottman, Gentner, & Goldwater, 2012) and developing a more integrated understanding (Krajcik & Shin, 2013; Linn & Elyon, 2011; Roseman, Linn, & Koppal, 2008). New evidence may necessitate students evaluating and adjusting their current explanations. As well, new evidence may require students to use new science ideas. As will be seen in this study, rethinking current ideas when faced with contradictory evidence may be quite challenging for many students. "Helping students learn disciplinary core ideas through engaging in scientific practices (such as explanations) will enable them to become less like novices and more like experts" (NRC, 2012, p. 25).

Writing earlier versions of the explanation may provide students with those experiences and the building of knowledge structures that prepare them to more fully utilize new science ideas when incorporating new evidence into an existing explanation, thus transferring their learning to new situations. Bransford and Schwartz (2001) emphasize thinking about transfer as "preparation for future learning" (p. 9). This thesis documents the process of students constructing one explanation, through multiple iterations, as new evidence is obtained, and examines the support a teacher provides to assist them as their explanations progress from being less to more sophisticated. The challenges that the students face are also documented.

1.3 Background of the Study

Guiding assumptions of the new Framework for K-12 Science Education (National Research Council (NRC), 2012) are that "knowledge and practice must be intertwined in designing learning experiences…" (p. 11), "development of understanding (occurs) over time" (p. 24), and that "students need….time…. to actually practice science..." (p. 25). This new document has been developed based on several other major science education documents (American Association for the Advancement of Science (AAAS) 2008; AAAS 1993; AAAS, 1989; National Research Council (NRC) 2008; NRC 2007; Bransford, Brown & Cocking, 2000; National Science Education Standards (NSES), 1996) that reflect advances in understanding how students learn as well as about the teaching of science. The Framework (2012) presents three dimensions: disciplinary core ideas, scientific and engineering practices, and crosscutting concepts (which are explained more fully in Chapter 2). When developing learning experiences for students these three dimensions need to be blended together; "Helping students learn disciplinary core ideas through engaging in scientific practices will enable them to become less like novices and more like experts" (NRC, 2012, p. 25). One such practice, constructing evidence-based explanations, is emphasized in all of the major science education documents. The Organization for Economic Co-operation and Development (OEDC, 2004) defines scientific literacy as the capacity to use science knowledge to identify questions and draw evidence-based conclusions in order to understand and help in decision-making about the natural world. Choi and colleagues (2011) introduced a framework for scientific literacy composed of five dimensions that includes many of the same components as the Framework and the OEDC. In addition, they stress metacognition and self-direction.

The goal is to enable students to understand core ideas of science and make numerous connections between these ideas. When students form connections between prior knowledge and new ideas, integrated understanding occurs that can be used by students to explain phenomena, solve problems, make decisions, and learn new concepts (Krajcik & Shin, 2013).

When students investigate a phenomenon they are responding to a question to explore and explain the natural world. The reason why the phenomenon occurs is based on evidence. Students, like scientists, can explain that phenomenon by constructing an evidence-based explanation. Using an explanation framework comprised of *claim, evidence,* and *reasoning,* and adding a *rebuttal* as students gain more experience, can assist students in constructing explanations (McNeil & Krajcik, 2011).

Supporting middle school students in this practice is challenging. Students need opportunities to make claims based on available evidence and then use science ideas to justify why the evidence supports the claim. Research shows that reasoning is the most difficult part of an explanation (Berland & Reiser, 2009; McNeill & Krajcik, 2006). In order to reason, students must have an understanding of science ideas; they should use this understanding to select certain data and show why these data count as evidence and also support the claim. This reasoning requires discussion of appropriate scientific ideas. Whether the science ideas that students hold are connected to other science ideas resulting in integrated understanding (Krajcik & Shin, 2013, Roseman, Linn, & Koppal, 2008) or if the ideas are merely isolated bits of unconnected facts will be reflected in the degree of sophistication of students' explanations of phenomena. Increasing interconnections between fundamental concepts and patterns reflect individuals with progressively sophisticated understanding in a domain (Chi, Feltovich, & Glaser, 1981; Hmelo-Silver & Pfeffer, 2004; Rottman, Gentner, & Goldwater, 2012). Understanding core ideas and crosscutting concepts through engagement in scientific practices, like constructing explanations, may help students to understand the broader and deeper levels of scientific knowledge and how to make use of that knowledge (Krajcik & Shin, 2013; NRC, 2012). Having an understanding of science ideas, however, does not guarantee that students will use that science knowledge to construct strong arguments or explanations (or solve problems or make decisions). Students must use ideas to build connections. An explanation framework, like that proposed by McNeil and Krajcik (2011), along with teacher scaffolding, can assist students because it provides a structure that is accessible to students (McNeill & Krajcik, 2009; Tabak, 2004).

Writing scientific explanations, particularly incorporating science ideas as part of reasoning and adjusting claims in light of new evidence, is a complex undertaking that requires time and feedback. To help students develop an integrated understanding of science ideas, practices, and crosscutting concepts, the importance of developing a curriculum with an iterative rather than sequential focus over time is viewed as paramount (Fortus & Krajcik, 2011). Understanding of and use of science and engineering practices does not develop with a single exposure. The same skills, or practices as referred to by the New Framework (2012), should be utilized multiple times across a series of tasks (Bransford, Brown & Cocking, 2000) to support students in building ideas over time.

Pellegrino, Chedowsky, & Glaser (NRC, 2001) stress the importance of practice and feedback. Learning, they say, is enhanced when students receive feedback specific to the qualities of their work and ways that they can improve their understanding. Practice and feedback are critical to the development of skills and expertise (Pellegrino et al., 2001). Feedback prompts students to consider new ideas, to expand their current thinking including making connections between ideas, and to reconsider current thinking, that may be inconsistent with their data or inconsistent with what scientists believe. Over time, and with various types of support from teachers, students' written explanations can become more sophisticated, reflecting more integrated understanding. A variety of distributed scaffolds provide multiple forms of support to students that allow them to do more sophisticated tasks, like constructing explanations, than they could normally do. These synergistic scaffolds work together to build understanding (McNeill & Krajcik, 2009; Tabak, 2004).

The most frequently described situations in the science education literature (Cavagnetto, 2010) where students construct multiple explanations reflect curricula where students write separate explanations throughout the curriculum based on evidence from different experiments about different phenomena. In contrast, students can explore one, more complex phenomenon in an authentic context. In order to fully understand and explain the phenomena, multiple pieces of evidence need to be collected and analyzed. Data are not collected all at once, but over a period of time (days or weeks). Students construct an explanation based on the available evidence, incorporating science concepts as part of the explanation. As more data are collected, students incorporate these findings into their existing explanation. So students construct one explanation, but over a period of time, with each iteration becoming progressively richer, they develop a more comprehensive understanding of the phenomenon. During the process, students revisit concepts that provide them with opportunities to expand or revise their thinking allowing their science understandings to progressively develop. With the additional evidence, students also need to build understanding of new science ideas. Teacher support, through classroom discussion, scaffolded guide sheets, and feedback throughout the process, assists students towards developing more connections between science ideas, resulting in more integrated understanding. As Obsorne (2014) states, "The reading, writing, and talking of science matter as much to the learning of science as engaging in empirical inquiry does" (p. 1835).

Writing earlier versions of the explanation may provide students with experiences and the building of knowledge structures that prepare them to more fully utilize new science ideas when incorporating new evidence into an existing explanation. Bransford and Schwartz (2001) emphasize thinking about transfer as preparation for future learning (PFL) with a focus on extended learning rather than one-time performance tasks. When they are well prepared for future learning, according to Bransford and Schwartz, students are more able to transfer that learning to a new situation. This new situation can be exploring a new aspect of more complex phenomena that is part of a system and that entails new science ideas and perhaps using new tools for further exploration and further learning.

The goal of constructing one explanation over time is to assist students towards developing integrated understanding utilizing the explanation framework as the vehicle by which students can be supported to develop the rich "story" of a particular phenomenon or a system under study. The aim is to assist students to learn how to develop (construct) the richest, evidence-based science "story" to explain the phenomenon. As students develop their explanation over time, not only do they have the potential to include more science ideas, but also to ensure that the science ideas may become more connected enabling students to tell a richer, more sophisticated account about the phenomenon. This places them on a trajectory to move from novices towards having more expertise (Brandsford & Schwartz, 2001).

1.4 Research Questions

This study is concerned with supporting students to develop integrated understanding through building a more sophisticated explanation over time. To achieve this aim, the study is designed in three parts and each part has its own research questions. The nine research questions presented below, therefore, are organized within chapters based on how they are analyzed and presented in the thesis.

Making Claims (Chapter 4)

1. How do students adjust their claim as new evidence emerges?
2. What are the patterns that students' claims progress through in the various iterations of an evolving explanation?

3. What are the challenges that students face in developing one claim over time?

Developing Understanding – Science Ideas (Chapter 5)

4. As students engage in writing an evolving explanation, how does their understanding of science ideas develop across time?
5. How does the practice of analyzing data/evidence and writing the first two iterations of an evolving explanation allow students to transfer their learning to new situations?

Integrated Understanding – Reasoning: Connecting Science Ideas with Evidence (Chapter 6)

6. How do students connect science ideas with evidence and are students able to make more connections to evidence over time?
7. Does the process of writing the first two iterations provide students with experience to make more connections of science ideas with evidence when writing about new evidence: Is there transfer?
8. How do the levels of understanding that students possess about science ideas relate to the connections to evidence that students make over time?
9. What is the impact of students' understanding of science ideas and/or connections on their ability to adjust claims when faced with new evidence?

1.5 Overview of Methodology

Fifty-eight, 7th grade students from an independent middle school in a small mid-western city participated in the study during the fall of 2011. The study utilized a time series research design (Creswell, 2009) with students writing four iterations of one explanation during a semester project where students investigated the water quality of a local stream; students expanded and revised one explanation over the course of six weeks as they collected more data and new evidence was obtained from various water quality measures. This explanation is termed an "evolving explanation" to reflect the revision and expansion process of the explanation. The explanation was embedded as part of the curriculum. The four iterations of the evolving explanation were collected for each student. Teacher feedback from the second and third iterations was also collected.

A comprehensive concept map of the science ideas was developed. From this concept map a rubric was created using a base rubric for analyzing scientific explanations (McNeill & Krajcik, 2011). Three water ecology experts evaluated both the concept map and the rubric for scientific accuracy and to establish validity. Three scorers, including the researcher, knowledgeable of the science curriculum and of the structure and use of scientific explanations in classrooms scored a subgroup of the explanations to obtain reliability. The researcher scored the other explanations. Measures were taken to avoid drift.

Various processes were used to analyze the data. Qualitative measures to look for commonalities and differences among the data were used. As a result various patterns emerged, particularly related to claims. Statistical analyses that included ANOVA using a repeated measure design, crosswise comparisons, and regression analyses were also conducted. These analyses were used to track the progress students made through the four iterations of the explanation related to building of science ideas, to determine whether or not students connected science ideas to evidence, and what was most predictive of claims students generated based on two, three, or four pieces of evidence. These analyses are expanded upon in later chapters.

1.6 Significance

This thesis makes several important contributions to the field.

This study sheds light on how to support students toward developing a more sophisticated, integrated understanding of science with an emphasis on constructing complex evidence-based scientific explanations that allow students to move towards becoming scientifically literate. The significant learning gains exhibited by students in this study provide an example of what this process can look like as students build a rich explanation to tell the evidence-based science "story" of the health of a stream for freshwater organisms.

Research from this study suggests that investigations that use evolving explanations can assist students to develop reasoning as part of developing an integrated understanding that allows them to explain phenomena.

Another contribution made through the study in this thesis is that it provides a rich example of a curriculum that utilizes 3-Dimensional Learning – the blending together of core ideas, scientific practices and crosscutting concepts – as the methodology of instruction proposed by the new *Framework for K-12 Science Education* (NRC, 2012) in the United States. How 3-Dimensional Learning is successfully used in the classroom will be of interest to researchers, curriculum designers, and teachers.

The curriculum investigated in this thesis utilizes an iterative focus in which students create explanations across a period of time; this study, then, supports research on the importance of developing iterative curricula materials to assist students towards building understanding that becomes richer and more sophisticated over time. In this way, the curriculum provides insights into the value of students using core ideas, explaining causal relationships, and engaging in the practice of constructing scientific explanations multiple times. This leads to another contribution of the thesis.

This study extends research on explanations. Current research looks at how students write multiple explanations in a unit, each focusing on different phenomena (Cavagnetto, 2010). Rather than writing multiple explanations, students in this study construct an evolving explanation, one explanation that is revised and extended as students gather additional evidence to explain one, more complex phenomena. This may be the study's most important contribution to the field. It is through writing evolving explanations that students develop more integrated understanding of the ideas that allows them to reason in a more sophisticated manner. There is no known research about students engaging in an iterative process of revising and expanding one explanation over time, as more evidence is collected. In this regard, the study broadens the field to explore students' constructing explanations within a context that aligns with the understandings about Nature of Science (NGSS 2013, Appendix H).

One more contribution that this thesis makes is to expand research to explore whether or not different experiences prepare students for future learning (Bransford & Schwartz, 2001). In this case, the study explored whether or not an evolving explanation allows students to use their learning to explain phenomena in new situations.

Finally, findings from this thesis illustrate the challenges these grade 7 students face, particularly in adjusting claims when presented with new evidence, and also in connecting science ideas with evidence. In addition to new questions that may emerge from these challenges for the research community, curriculum designers and teachers will find the outcomes of interest as they develop curricula that utilize evolving explanations including how to best support students in this complex practice.

1.7 Overview of the Thesis Document

Chapter 1 presented an introduction and overview of the study. Chapter 2 provides a thorough review of the literature. In Chapter 3, the general research methodology is discussed. This general research methodology, however, is further articulated in the three chapters that follow. The thesis is designed in three parts, with various methods closely tied to specific data analyses. As such, each of these parts of the study has its own chapter, with research methodology specific to that portion of the study. In addition, data analyses, findings, and a discussion of the findings is included in each of these chapters. Chapter 4 presents research that explores how students modify their claims as new data are collected and analyzed to provide additional evidence as well as the challenges that students face in developing one claim over time. Chapter 5 explores the development of students' science ideas across the four iterations of the explanation to investigate their development towards understanding of science ideas and relationships between those ideas from less sophisticated to more sophisticated understanding over time. Chapter 6 focuses on reasoning. It examines, over time, whether or not students are able to use their understanding of science ideas to make connections to evidence. Whether science ideas impact the amounts of connections students make to evidence is also explored. Then ultimately, the impact of science ideas and/or connections to evidence on students' ability to adjust claims when faced with new evidence is investigated. These findings are then tied in with findings discussed in Chapter 4 that focuses on claims. Finally, Chapter 7, the conclusion chapter, summarizes the findings of the research questions, discusses implications for both research and teaching, and proposes possible research questions for those interested in pursuing further research related to findings from this study.

CHAPTER 2

Literature Review

2.1 Overview of the Chapter

In this chapter, I review the literature focused on development of integrated understanding that includes how knowledge develops over time, and how knowledge can prepare students for future learning, in other words, transfer. These issues are related to social constructivism. Blending practices with core ideas of science when designing learning environments, referred to as three-dimensional learning (NRC 2012), is explained and discussed. The chapter also includes literature related to scientific explanations including challenges for students and use of scaffolds to support students. The chapter culminates by proposing a new facet of explanations, termed evolving explanations, as a means of assisting students to make sense of more complex phenomena.

2.2 Introduction

Helping students to develop integrated understanding, where students make more and more connections between ideas, assists students to make sense of and then use those understandings to explain phenomena and solve problems (Bransford, Brown, & Cocking, 2000; Fortus & Krajcik, 2011; Hmelo-Silver, & Pfeffer, 2004; Roseman, Linn, & Koppal, 2008). Over the past two decades there have been great advances that provide insights into how students learn as well as how to effectively teach science resulting in many publications (American Association for the Advancement of Science, AAAS, 1993, and *Science for All Americans* 1989; Bransford, Brown & Cocking, 2000; National Research Council, NRC 2007; NRC 1996; Michaels et al., 2007). Experts are able to understand and explain phenomena and work on solving problems because they have well-organized knowledge structures and are able to apply their understandings (Bransford, Brown & Cocking, 2000; Chi, Feltovich, & Glaser, 1981; Hmelo-Silver & Pfeffer 2004). For students, classroom experiences often do not foster the development of these knowledge structures nor do they encourage students to apply the understandings they hold. This makes it difficult for students to use their emerging understanding to explain phenomena during class or in new situations.

How do we assist students towards developing this level of knowledge? The *Framework for K-12 Science Education* from the United States (NRC, 2012) introduces Three-Dimensional Learning, the working together of scientific and engineering practices, crosscutting concepts, and disciplinary core ideas, and recommends that all aspects of students' science experiences, K-12, be built around these three dimensions (a more complete discussion of 3-dimensional learning may be found later in this chapter). The Framework guided development of the Next Generation of Science Standards (NGSS, 2013) is intended to inform curriculum development, classroom instruction, and assessment. The Framework (2012) was developed from a synthesis of many major science education documents including, *Ready, Set, Science,* (Michaels, Shouse, & Schweingruber, 2008) *Taking Science to School*, (NRC 2007), *How People Learn: Brain, Mind, Experience, and School* (Bransford, Brown & Cocking, 2000), the *National Science Education Standards* (NRC 1996), the AAAS Project 2061 *Benchmarks* (1993), and *Science for All Americans* (1989). All of these documents stem from research based on current understanding of both the teaching and learning of science as well as research in learning science, education, and cognitive psychology. Constructing evidence-based explanations to help students make sense of phenomena is emphasized as an important scientific practice in these documents. The capacity to use science knowledge to identify questions and draw evidence-based conclusions in order to understand and help in decision- making about the natural world and changes made to it through human activity is how the Organization for Economic Co-operation and Development (OEDC, 2004) defines scientific literacy. This definition is consistent with the Strands of Scientific Proficiency laid out by the NRC (2007) and with the Framework (2012).

2.3 Integrated Understanding/Knowledge Structures

Whether termed integrated understanding, knowledge structures, or a conceptual framework, there is much research to illustrate that expert scientists have highly developed integrated understandings that allow them to explain phenomena and solve problems. Students' knowledge structures, on the other hand, are often composed of nonintegrated, disconnected bits of information and assisting students towards developing integrated understandings is a major goal of science education (Bransford, Brown & Cocking, 2000). Fortus and Krajcik (2011) define integrated understanding as "ideas connected to each other in such a manner that allows learners to be aware of and be able to use relationships between various ideas to solve problems and understand the world they live in" including explaining phenomena. Roseman, Linn, & Koppal (2008) suggest that students have integrated understanding when they realize science ideas are connected and make deliberate efforts to apply their understanding of science ideas in order to explain phenomena. However, Hmelo-Silver and Pfeffer (2004) suggest that experts' understanding of complex systems differ from that of novices; expert understanding consists of a constructed network of concepts and principles. "Expertise involves well-organized knowledge…. Knowledge is organized around core concepts or 'big ideas' that guide their thinking about their domains" (Bransford, Brown & Cocking, 2000, p.36). Part of why experts know more is because their well-organized knowledge allows them to more easily access the information with procedures for applying organized knowledge in various contexts (Chi, Feltovich, & Glaser, 1981). They surpass novices in their use of corroborating evidence (Bransford, Brown & Cocking, 2000). In other words, to be knowledgeable in a domain suggests that one's knowledge is progressively structured and integrated. This knowledge includes two components: 1) science ideas that are connected together, and 2) the application of those understandings to specific situations. The goal of the teacher in this research study was to assist her students towards developing this integrated understanding.

2.4 How Do Students Construct Understanding? Social Constructivism

Vygotsky, a Russian psychologist, developed social constructivist theory (Vygotsky, 1986, 1978). Through his work he concluded that children develop understanding through social contexts where students play an active role in learning. These social contexts include interactions with people around them – their peers and adults. Children also interact with the world around them and make interpretations based on those interactions. As active participants in constructing understanding, students need to experience a phenomenon in order to make sense of it and to develop that understanding. Vygotsky referred to a *More Knowledgeable One* (MKO) as someone with more expertise in an area who could assist the learner in developing understanding. Learning, according to Vygotsky, occurs in the Zone of Proximal Development (ZPD) (1978), what a learner can do with help, verses what she can do alone or what a learner cannot do. In the Zone of Proximal Development, students are able, with support, to complete challenging tasks.

Teaching based on social constructivist theory suggests that when designing learning experiences, teachers should develop curriculum where students actively engage with phenomena and collaborate with each other and the teacher to make sense of ideas that would then foster students towards constructing integrated understanding. This approach is consistent with the 3-dimensional learning, discussed below (NRC 2012). Students need multiple opportunities that provide them with experiences and time to collaboratively construct and reconstruct knowledge, to explore and express their ideas, in a learning environment that encourages students to think about and revise their own understanding of phenomena (Krajcik & Czerniak, 2014).

2.5 Developing Understanding Over Time

Sophisticated understanding does not develop in a short period of time, but instead, slowly develops over time as an individual grapples to make meaning. To help students develop integrated understanding, curriculum developed with an iterative rather than sequential focus over time is paramount (Bransford, Brown & Cocking, 2000; Fortus & Krajcik, 2011; NRC, 2013; Nelson & Hammerman, 1996). Learning complex ideas takes time and often occurs when students work on a meaningful task that forces them to synthesize and use ideas (Bransford, et al., 2000; Krajcik & Shin, 2013). Developing instructional materials that place students in a context where "old" ideas are revisited as new ideas are added allows students' science understandings to progressively build. This view - that students' understanding of science ideas is an emergent process - is consistent with social constructivist theory (Vygotsky, 1986). The Framework (2012, p. 11) clearly posits that a development of understanding occurs over time (p. 24), as students need…."time…. to actually practice science." (p. 25).

Similarly, understanding of and use of science and engineering practices does not develop with single exposures. Practices need to be used in multiple contexts (NRC, 2014). Bransford and colleagues (2001) refer to various skills being cycled and recycled or utilized multiple times through different tasks. The New Framework replaces the term “skills” with “practices” to “emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice (NRC, 2013 p.30). The practice of writing scientific explanations, particularly applying science ideas as part of reasoning, is a complex undertaking that requires time and feedback. For students to develop a strong understanding of science ideas and then to apply those ideas in their reasoning within the practice of developing a scientific explanation requires students to construct explanations repeatedly and in different contexts. This process exemplifies knowledge-in-use and illustrates that content and practice are explicitly linked (NRC, 2012). Equally as important, the process of constructing explanations can assist students to develop deeper understanding of science ideas as it encourages them to make more and more connections by seeing relationships and patterns between those ideas. This iterative process, with multiple opportunities and with different contexts, facilitates students to move away from understanding science ideas as bits of disconnected facts towards organizing their knowledge around core science ideas in much the same way that experts do (Chi, 2011; Hmelo-Silver & Pfeffer, 2004; Rottman, Gentner, & Goldwater, 2012). When ideas are disconnected, they are neither accessible nor useful to explain phenomena or solve problems.

2.6 Transfer: Preparation for Future Learning

Having integrated understanding is important because it allows individuals to apply their understandings to new situations. If we can assist students to develop an integrated conceptual framework, this will make new learning easier and also allow them to use their understanding. There will be greater transfer, the ability to extend what has been learned in one context to new contexts (Brandsford, Brown, & Cocking, 2000) if science ideas are organized into a conceptual framework. This conceptual framework will also help students to apply what they have learned in new situations and learn associated ideas more quickly (NRC, 2001 p. 17). Bransford and Schwartz (2001) emphasize thinking about transfer as “preparation for future learning" (PFL) with a focus on "extended learning" rather than one-time performance tasks (p. 19). When students are well prepared for future learning, they state, they are more able to transfer that learning to a new situation. This new situation can be exploring a new portion of a more complex phenomenon that is part of a system and that entails new science ideas and perhaps the use of new tools for further exploration.

2.7 Three Dimensional Learning, Nature of Science, Performance Expectations, & Project-Based Learning

If we want students to develop usable organized knowledge structures that allow them to transfer their understanding to new situations - and we also realize this takes time - then we need to design curriculum that supports these goals.

2.7.1 Three-Dimensional Learning

Three-dimensional learning can support these goals. The guiding assumptions of the new *Framework for K-12 Science Education* (2012) are that "knowledge and practice must be intertwined in designing learning experiences…" When designing curricula we should create classrooms that are knowledge-centered environments that encourage doing with understanding (Bransford, Brown, & Cocking, 2000, p. 24) and utilizing curriculum materials that assist students to develop connections among science ideas and then to apply their understandings to make sense of the world (Roseman et al., 2008, p. 13). Towards this end, the New Framework (2012) presents three dimensions: scientific and engineering practices, crosscutting concepts, and disciplinary core ideas. Figure 2.1 is a representation of the three dimensions.

Practices include both science and engineering practices that scientists utilize to conduct their work, for example, asking questions and defining problems, constructing explanations and designing solutions, among others. As students engage in science and engineering practices they should see how crucial they are in addressing major challenges that society faces today. One such challenge is maintaining clean water supplies (Framework p. 9). Engaging in practices (like constructing explanations) are also challenging for students and can their enhance learning, but as Osborne states, are rarely part of school experiences (2014).

Seven crosscutting concepts such as patterns, cause and effect, and stability and change (NRC 2012, p. 84) have applications across all domains of science and may be thought of as unifying concepts or common themes. These and others crosscutting concepts are found in any discipline.

Disciplinary core ideas are a small set of core ideas in science and engineering and are grouped into "four major domains: physical sciences; life sciences; earth and space sciences; and engineering, technology, and applications of science (p. 31)." These represent a limited number of science ideas that will allow students to continually build on and revise their understanding over their K-12 science experience.

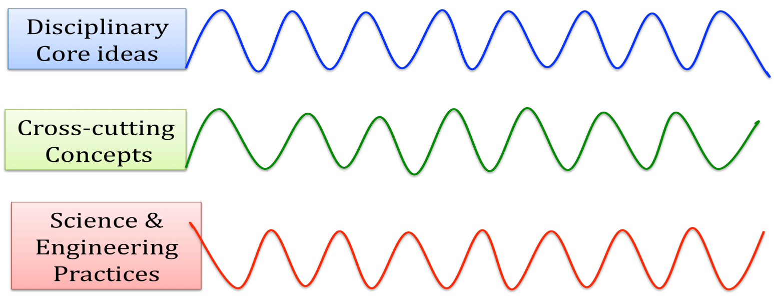

Figure 2.1: The Three Dimensions of Learning (Framework, 2012)

The NGSS states, "The real innovation in the NGSS is the requirement that students operate at the intersection of practice, content, and connection (NGSS 2013 introduction, p. xvi)". In other words, a student cannot learn one without the other. When developing learning experiences for students, these three dimensions need to work together as illustrated in Figure 2.2. This is called 3-dimensional learning. If teachers engage students to use scientific practices as the means to learn disciplinary core ideas this will facilitate students to move from novices to more like experts (NRC 2012, p. 25). In addition, if used in a collaborative environment, where students work with each other and with the teacher to explore the phenomenon, students will be part of classroom instruction based on social constructivism (Vygotsky, 1986). They will build the knowledge structures that will aid them in designing solutions to problems, explaining phenomena, and preparing them for future learning as they become progressively more scientifically literate. These are the same goals that are articulated as *Scientific Proficiency Strands* from the NRC's, *Taking Science to School* (2007). The framework presents four strands that are intertwined to describe a student who is proficient in science and emphasizes "science as practice" (p. 38).

Developing curricula using 3-dimensional learning can provide students with experiences that assist them to develop understanding of core ideas of science and make numerous connections among these ideas. When students form connections between prior knowledge and new ideas, integrated understanding is formed that can be used to explain phenomena, solve problems, make decisions, and learn new concepts (Krajcik & Shin, 2013).

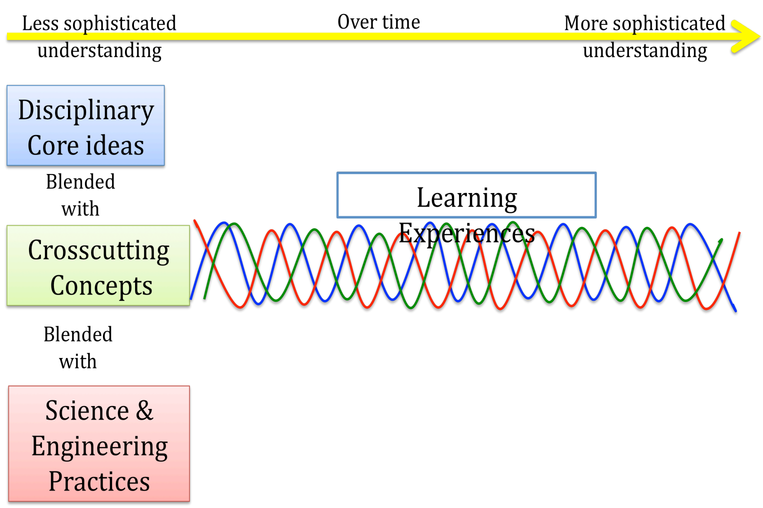

Figure 2.2: 3-Dimensional Learning: Experiences that Blend the Three Dimensions

2.7.2 Nature of Science

A scientifically literate person should also be able to understand the nature of science. A supporting document, the *Nature of Science Matrix* (NGSS 2013, Appendix H) is included with the NGSS. One component of Nature of Science states, "Scientific Knowledge is Based on Empirical Evidence" (p. 97). A second component stresses that in light of new evidence, scientific knowledge is open to revision (p.97); these are two of eight, *Nature of Science* components included as part of the NGSS. Science is an evidence-based field where ideas evolve over time - weeks, years, even decades and centuries - as new evidence emerges. It is important for students to gain experience that allow them to develop understanding of the nature of science.

2.7.3 Performance Expectations

The NGSS integrates the three dimensions into what are called performance expectations. These are articulations of what students should be able to do at the end of instruction over a several year period and realized through curricula that is at the "the intersection of practice, content, and connection" (p. xvi NGSS). What students experience throughout curricula across the grades should build towards these performance expectations. Krajcik and colleagues (Krajcik, McNeill, & Reiser, 2008) blend practices and knowledge into what they call learning performances to illustrate what students should be able to do as a result of instruction. They use learning performances to help design instruction (Krajcik, et al., 2008) for a particular project within a given year.

The learning environment that the teacher designed, explored in this thesis, utilized 3-dimensional learning and students' learning performances included using science ideas to construct an explanation of a complex phenomenon, a local stream. As well, the instructional context that students' experienced worked to build toward several performance expectations (discussed in Chapter 3). It is not enough for students to "know" science ideas; they need to show that they can use that knowledge. If implemented properly, the NGSS will result in students who are able to develop and apply scientific knowledge to new and unique situations and to think and reason scientifically.

2.8 Project-Based Science

Engaging students in 3-dimensional learning to construct integrated understanding of science, as envisioned by the Framework for K-12 Science Education (NRC 2012) and the NGSS (2013) can be accomplished utilizing project-based science as the method of instruction. Also called project-based learning, the Project-Based Science

(PBS) (Krajcik & Czerniak, 2014, Krajcik & Blumenfeld, 2006) approach engages learners in exploring important and meaningful questions by asking questions, designing and carrying out investigations, analyzing, interpreting, and communicating findings through producing various artifacts that both promote and illustrate student learning. PBS situates learning in a real-world context where students find answers or solutions to meaningful questions, called driving questions (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991; Krajcik, & Mamlok-Naaman, 2006).

In the process of answering these questions, students engage in learning important science ideas. As students explore the driving question and sub-questions, they actively construct understanding by utilizing practices and crosscutting concepts through long-term investigation and collaboration. Teachers assist students towards understanding through benchmark lessons: teacher directed activities used to introduce important concepts, principles, or skills (Krajcik & Czerniak, 2014). PBS parallels what scientists do and exemplifies classroom instruction that includes the nature of science and the blending of core ideas, practices, and crosscutting concepts, thus 3-dimensional learning, as envisioned by the New Framework for K-12 Science Education (2012) and more thoroughly specified in the Next Generation of Science Standard (NGSS, 2013). Through PBS, which shares the same guiding principles as 3-dimensional learning, students apply scientific ideas to investigate and explain real world phenomena and solve real world problems, exactly what is needed to develop scientifically literate people.

Project-based science is the methodology of instruction in the classroom of this study. Students explored the driving question, “How healthy is our stream for freshwater organisms?” where, through 3-dimensional learning, students used the practices of asking questions, planning and carrying out investigations, analyzing and interpreting data, and constructing explanations. The crosscutting concepts of patterns, systems, and cause and effect were an integral part of the investigation. Students used both the scientific practices and crosscutting concepts to explore disciplinary core ideas related to earth and physical science (more specific discussion of these dimensions will be articulated in Chapter 3). These specific aspects of the dimensions worked together to assist students to develop integrated understanding of a complex phenomenon that included a freshwater stream and peoples' land use practices that could impact the stream. This thesis focuses on students' explaining this phenomenon by constructing an explanation, over the course of several weeks, as more and more data were obtained.

2.9 Constructing Explanations

Students build understanding when they are given opportunities to express, clarify, justify, interpret, and represent their ideas (NRC 2007). Constructing written explanations to explain phenomena is one such opportunity. The Framework (NRC 2012) emphasizes that explanations in science are causal, ascertaining the underlying chain of cause and effect. Reflecting on and responding to peer and teacher feedback, be it orally or in written form, can also assist students (NRC 2007). Eight scientific practices are presented in the Framework (NRC 2012), over half of which are related to explanations: Asking questions and defining problems (Practice 1), Analyzing and interpreting data (Practice 4), Constructing explanations (Practice 6), Engaging in argument from evidence (Practice 7), and Obtaining, evaluating, and communicating information (Practice 8). Science classrooms need to provide students with "engaging opportunities to experience how science is actually done" (NRC, 2012). Engaging in constructing explanation is one way for them to experience science. Other major science education documents also emphasize constructing evidence-based scientific explanations (AAAS Project 2061 Benchmarks, 2008; NRC 2007; NRC, 1996; Michaels et al,. 2008). Constructing explanations serve as an important scientific practice that brings meaning to all that scientists do. Providing students with experiences with scientific explanation is a fundamental component of scientific inquiry (Duschl & Osborne, 2002). Students' constructing explanations, receiving feedback, and then revising their explanations is a central instructional component of the research in this thesis.

Studying explanation and argumentation strategies in classrooms has resulted in many research studies. Cavagnette (2010) conducted a literature review of 54 articles to analyze characteristics of argument-based interventions for scientific literacy in K-12 settings. Most of these studies were in classrooms where students engaged in culminating activities designed for students to apply their understandings (Bell &

Linn, 2000; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000). Some of these culminating activities were explanations of phenomena (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000). Some were related to computer simulations (Bell & Linn, 2000). In other studies, students constructed explanations of phenomena several times; these activities were embedded in the curriculum (Berland & Reiser, 2009; McNeill et al, 2006; McNeill, 2008; McNeill & Krajcik, 2008). The explanations were generally a paragraph or two. The process worked to assist students to develop understanding of science concepts and of constructing explanations. The evidence obtained by students was related to different phenomenon for each explanation; they wrote a separate explanation for each activity in which they participated.

Explanations that student constructed in the research reported in this thesis are also embedded throughout the curriculum. Different from other studies, however, students in these classrooms constructed four iterations of one explanation that was based on developing understanding of a complex phenomenon where students collected data over a few weeks time. The research focus in this thesis is on investigating the process of how students' understanding develops over time as they construct this scientific explanation and includes the development of understanding of science ideas, how students connect those ideas with evidence (reasoning), and if and how claims are adjusted in light of new evidence. The literature clearly shows that students need support when constructing explanations. Based on the review of the literature, however, no studies were found where students write and revise one explanation over time, as new evidence emerges.

2.9.1 An Explanation Framework

McNeill and Krajcik (2011) present an explanation framework, based on Toulmin's argumentation model (1958). Toulmin's model included six components; claim, ground (the data), warrant, backing, rebuttal, and qualifier, McNeill and Krajcik adapted this model to develop a framework with language that is more accessible to students and that provides support for students to construct scientific explanations to explain phenomena. The framework is comprised of four components: *claim, evidence, reasoning, and rebuttal.* A claim is a statement that answers a question or is a conclusion about a problem. Evidence is scientific data that supports the claim. Reasoning shows why the data counts as evidence to support the claim by using scientific principles and reasoning to connect the claim to the evidence. Reasoning combines Toulmin's (1958) warrant and backing. In reasoning, students apply appropriate science ideas to explain how their evidence supports their claim, thereby connecting the science ideas with the evidence. A rebuttal rules out other explanations. The framework is more than a support structure for writing explanations; the framework is designed to support students in sense making (Berland, & Reiser, 2009).

Even with an explanation framework as a guide, writing explanations is a challenge for students (McNeill & Krajcik, 2011). They need help to make appropriate claims, support to include appropriate and sufficient evidence, and assistance to incorporate reasoning by using science concepts to discuss their evidence, and consider alternative explanations and rebuttals. In the following sections I will discuss some of the challenges students face related to claims and reasoning. Following those will be a discussion about synergistic scaffolds that teachers can utilize to support students.

2.9.2 Claims

The "claim" portion of the *claim, evidence, and reasoning* framework is viewed as the aspect that most students are able to respond to accurately (McNeill & Krajcik, 2011; Berland, & Reiser, 2009; McNeill & Krajcik 2007; McNeill et al 2006). Students are most often presented with evidence, consult books or other resources, or collect their own data to make claims about a phenomenon as they develop an explanation (Cavegnette, 2010) that is typically a good paragraph or two. The data that are collected or with which students are presented tends to be consistent rather than contradictory; that is, the evidence usually clearly supports a certain claim because it consistently points toward the same claim. Students then should be able to construct an explanation of the phenomenon using an appropriate claim. Deciding on the best explanation, one that is reflective of all available evidence and part of which includes the claim, sometimes necessitates argument (NRC 2012). Allowing students to develop arguments based on their own experiences, such as observing a phenomenon as a class or in the form of individual or small group experiments, and then bringing student groups together to support and defend their thinking, and then build new arguments together, that then can be used to develop explanations of phenomena, assists students to build knowledge through meaningful engagement and interaction (Reiser, Berland, & Kenyon, 2012).

Having various student groups explore different portions of larger phenomena, develop their ideas, and then bring them to the larger group for classroom discourse and consensus building (Jimenez-Aleixandre & Pereiro-Munoz 2002) is another example that allows students to build scientific knowledge. In this study, different groups of students evaluated a particular dimension of a wetland environment then came together to share their portions and together develop claims. Both of these types of explanations have "claims that were logically bound by the evidence provided" (Berland, & Reiser, 2009. p.22). Chinn and Brewer's research findings show that students make predictions or share initial ideas based on their current understandings as part of their pre-instructional beliefs, and then, through either direct instruction or from an experiment, if ideas or evidence are inconsistent with their thinking students then ignore or in other ways discount the idea or evidence (Chinn & Brewer 1993, 1998). Scientists themselves can be challenged in making a paradigm shift in the face of anomalous data (Kuhn, 1996).

Research that is reported related to challenges students face to generate appropriate claims is often within the context of socioscientific issues where students are presented with conflicting information from different sources. For example, Sadler, Chambers, and Ziedler (2004) studied high school students who read different reports about the status of global warming. These reports contradicted each other.

In the study for this thesis, all students collected data about a phenomenon and made a claim as part of an initial explanation they constructed to explain the phenomenon. Then, all students collect additional data about the same phenomenon and needed to determine whether or not they needed to adjust their current thinking about the phenomenon that might also dictate that they adjust their claims. Altogether, students engaged in four cycles of data collection. Their original claim could have been accurate based on the available evidence used to construct their early explanation.

New data, however, could have been rendered the original claim and also subsequent claims unsupportable.

Research in science education, to my knowledge, does not indicate whether or not students adjust their current thinking and modify their claims when all the participants collect data about a phenomenon and then make a claim as part of an explanation and then collect additional data; this is the procedure students underwent in this study.

The actual work of scientists involves a continual process of revising claims as new evidence is collected and analyzed. Students need similar experiences as part of their science education experience; however, these types of experiences are not what students typically experience in classrooms. If students investigated a more complex phenomenon where they collected different data, over time, and constructed an explanation that would need to be modified as new evidence was collected it would match 3-dimensional learning (NRC, 2012) including aspects of Nature of Science (Appendix H, NGSS). That is, students use the practice of constructing an explanation over time to develop understanding of disciplinary core ideas while looking for patterns and causal relationships throughout: practice, crosscutting concepts, and disciplinary core ideas blended together in a meaningful learning context where students work to make sense of the natural world by using their understandings to explain phenomena.

Sometimes, new evidence emerges for the phenomena that contradicts students' claims and necessitates that students change their thinking and thus their claim. Such is the case in this study. Each time new data were obtained and analyzed students needed to examine if their claim accounted for all available evidence (Duschl, 2007; Sampson & Clark, 2006). This process more accurately mirrors what expert scientists do. Brandsford and Schwartz (2001) refer to negative transfer and "letting go" when "adapting to new situations" (p. 21). These new situations refer to transfer and preparation for future learning that often involve "letting go" of previously held ideas and behaviors." Although their research is not specific to claims, the idea can be applied to them; students need to be able to let go of current stated claims if new evidence no longer supports those claims.

Before students can let go of current claims, however, a reflective component may need to be added to learning. Metacognition may play a role in whether or not students detect incongruities or anomalies (NRC, 2007). Metacognition refers to thinking about the way one thinks. It is included as one of five dimensions for scientific literacy proposed in South Korea (Choi, Lee, Shin, Kim & Krajcik, 2011) emphasizing the need for students to regularly reflect and ask themselves if they understand or if they need more information. “Gathering data that exposes students to unexpected discrepant events (can be a way) of sending signals to students that they need to stop and think, step outside…to a more metaconceptual (mode that assists them to): question, generate, examine alternatives, and evaluate” (NRC, 2007 p. 112). This same strategy may be useful to assist students to reflect about their claims. Combined with classroom discourse that allows students to engage in argumentation to support and defend their thinking (Reiser, Berland, & Kenyon, 2012) and to discuss and critique their claims (Berland, McNeill, Pelletier, & Krajcik in press) could assist students to reflect about their current claims, reconcile disagreements, and then build new claims together.

Exploring natural systems and collecting real data, in real time, may naturally expose students to inconsistent data as additional evidence provides a more comprehensive picture of the phenomenon. Water quality data collected from a stream can easily have mixed results, with some measures reflecting positive, hospitable conditions for freshwater organisms while others are problematic, depending on the water quality measure; these are exactly the results students in this study obtained. Students’ claims about the health of the stream for organisms need to reflect all of the evidence obtained.

In summary, the claim portion of explanations has been seen as the most easily accessible to students. Situations typically described in science education literature focus on how to assist students to use evidence and reasoning when developing explanations. When investigating more complex systems, however, students’ claims may need to evolve as new evidence comes to light.

2.9.3 Reasoning: Scientific concepts connected to evidence

The reasoning portion of the *claim, evidence,* and *reasoning* framework is particularly challenging for students. In order to reason, students must apply their understanding of science ideas. Students need opportunities to make claims based on available evidence and then use science ideas to justify why the evidence supports the claim. The "reasoning" portion of the explanation framework, therefore, includes both science ideas and connecting those science ideas with evidence. Research shows that reasoning is the most difficult part of an explanation (Berland & Reiser, 2009; Gotwals & Songer, 2006; NRC 2007; McNeill & Krajcik, 2006). A primary prerequisite on reasoning is what students understand of casual relationships (NRC, 2007). As Gotwals & Songer (2006) found, an interaction between domain specific knowledge and reasoning exists. In order to reason, students should use their science understanding to select certain data and show why these data count as evidence and also support the claim. They need to provide a logical connection, or link as it is often referred to, between evidence and reasoning. This reasoning requires discussion of appropriate scientific ideas; students should use science ideas to think about and then explain their evidence. Generating a claim, then, should follow as part of a logical progression. This necessitates that students *use* their knowledge, thus *apply* their understanding.

Understanding science ideas and connecting those science understandings to evidence, blending them together, may account for students being so challenged to provide reasoning for their claims. This difficulty may be the key to whether or not students can *use* their knowledge. Integrated understanding of ideas is vital to understanding phenomena. Furthermore, gaining insight into challenges of reasoning may also provide insight into students' success or lack thereof to adjust claims in light of new evidence.

Whether the science ideas students hold are connected to other science ideas resulting in integrated understanding (Roseman, Linn, & Koppal, 2008) or if the ideas are merely isolated bits of unconnected facts will be reflected in how sophisticated students' explanations of phenomena will be. The process of constructing explanations and revising those explanations in light of new evidence assists students to form more integrated understanding that should result in more sophisticated explanations of the phenomenon because it assists students in sense making (Berland, & Reiser, 2009).

Developing understanding of core ideas and crosscutting concepts through engagement in scientific practices, like constructing explanations, help students to understand the broader and deeper levels of scientific knowledge and how to make use of that knowledge (NRC, 2012; Krajcik & Shin, 2013); the result is development of an integrated understanding. Knowing science ideas, however, does not guarantee that students will be able to make use of those ideas to construct strong arguments or explanations (or solve problems or make decisions). To make use of knowledge those understandings need to be evident as well-organized knowledge structures.

2.9.4 Explanation vs. Argumentation

There has been recent discussion about the difference between explanation and argumentation. Osborne and Patterson (2011) describe this as confusion in the field where some use these words interchangeably. The Framework for K-12 Education (2012) states that "Scientific explanations are accounts (that) explain observed relationships between variables and describe the mechanisms that support cause and effect inferences about them" (p. 67) and "students should…develop…evidence-based explanations (as) an essential step in building their own understanding of phenomena (p. 69). The idea that explanations focus on causal accounts is consistent among researchers (NRC, 2012; Obsorne & Patterson, 2011; Reiser, Berland, & Kenyon, 2012). According to the Framework (2012), when competing explanations exist for the same phenomenon students should engage in argumentation to decide which explanation is the best. This is consistent with Osborne and Patterson (2011) who suggest that when an explanation is in doubt or is contested, argumentation is necessitated. A controversy exists that motivates students to defend their own and challenge other's alternatives (Berland & Reiser, 2009). Part of argumentation is working towards reconciliation of differences to reach the strongest answers to questions being investigated (Berland, McNeill, Pelletier, & Krajcik, in review). Unlike arguments, Obsorne & Patterson (2011) state that explanations are not developed to persuade but, rather, to answer a question that is being explored.

This thesis focuses on students constructing an explanation where students work to make sense of their data by providing a causal account (NRC, 2012, Osborne & Patterson, 2011; Reiser, Berland, & Kenyon, 2012) as part of reasoning to explain a complex phenomenon. They are working to answer the questions, "*How healthy is the stream for freshwater organisms?"* No element of persuasion was included in the curriculum. The purpose of developing the explanation was to assist students towards developing integrated understanding of the science ideas utilizing practices. Therefore, the thesis does not incorporate argumentation as part of its discussions. The only exception, however, is related to claims. Students in these classrooms did not participate in classroom discussion to debate and justify their claims. They were asked to reflect, with partners, to determine if their claims needed to be adjusted as new evidence emerged. Assisting students to engage in argumentation to reflect on the claims is one suggestion for a teaching strategy that may help students to reflect to see if their claims accurately reflect all of the available data (Duschl, 2007; Sampson & Clark, 2006).

2.10 Synergistic Scaffolds

Being able to understand and explain phenomena is challenging. Scaffolds allow students to undertake tasks that they would simply not be able to do on their own (Bransford, Brown, and Cocking, 2000; Quintana, Reiser, Davis, Krajcik, Fretz, Duncan, Kyza, Edelson, & Soloway, 2004; Tabak, 2004; Wood, Bruner, & Ross, 1976). They assist learners not only to accomplish complex tasks but also to learn from these tasks. Scaffolds are various supports that a teacher, as a more knowledgeable individual, provides to help to focus students in productive ways; without these supports students may overlook important aspects of a task or only superficially address them (Reiser 2004). Although the actual term "scaffolding" was introduced by Wood, Bruner, and Ross (1976), the concept of scaffolding stems from Vygotsky's (1986, 1978) work that emphasized the role a more experienced person could play to assist a novice to learn concepts that would not otherwise be accessible to that learner without support from the more expert person.

Teachers can play an important role is assisting students to explain phenomena. They can incorporate intentional strategies to assist students to make connections that allow them to construct understanding that builds over time as part of sense making. Tabak (2004) refers to distributed scaffolds as multiple forms of support that are provided through different means to assist students in developing “disciplinary ways of knowing, doing, and communicating.” Guided learning experiences and social interaction assist learning (Bransford et al, 2000). These multiple forms of support can work synergistically to assist students to build stronger understanding (Quintana et al, 2004; McNeill & Krajcik, 2008, 2009; Tabak, 2004) in much more effective ways than they would if only utilized independently. What are various scaffolds? The explanation framework and how teachers introduce students to explanations, classroom discussion, teacher prepared guide sheets, and teacher feedback to students, are all forms of scaffolds that, combined, can assist students to take part in complex tasks such as understanding and explaining phenomena. Over time, and with various types of supports from teachers, not only will students’ written explanations become more sophisticated, reflecting more integrated understanding of the science ideas but ultimately, students should become more independent in constructing explanations to explain phenomena. Therefore, scaffolds should fade over time, as students become more proficient. I discuss various scaffolds in the sections below.

2.10.1 Explanation Framework and Introducing it to Students

Students need support that assists them to include appropriate and sufficient evidence, use reasoning that applies science concepts to explain evidence, consider alternative explanations and rebuttals (McNeill & Krajcik, 2011) and generate appropriate claims when explaining phenomena. One such scaffold is the explanation framework like that proposed by McNeil and Krajcik (2011). Along with teacher scaffolding, the framework can support students because it provides a structure that is accessible to them (Tabak, 2004, McNeill & Krajcik, 2009). The teacher can incorporate intentional strategies to assist students to understand the value and structure of explanations. The claim, evidence, and reasoning framework breaks down the essential components of constructing explanations, making those components salient to learners (Quintana, et al., 2004). Modeling scientific explanations, making a clear rationale for creating explanations, defining explanations, and using examples to illustrate the connections between everyday explanations and science explanations, are instructional practices that assist students (McNeill & Krajcik, 2008). In particular, the way teachers define scientific argumentation effected students' ability to write scientific arguments and explanations to explain phenomena by using both appropriate evidence and reasoning (McNeill K, 2008).[1] The use of *The Explanation Tool* framework (Windschitl, Thompson, & Braaten. 2011), influenced by both Vygotsky (1978) and Toulmin (1958), helped make explanations clear to novice teachers. The framework included prompts that helps students describe "what" happened (evidence) and explain "how" and "why" things happened (reasoning). It also assisted teachers to focus on central core ideas of science (Windschitl et al., 2011). Over time, scaffolds should fade (McNeill, Lizotte, Krajcik, & Marx, 2006) as students gain experience and familiarity with constructing explanations. In fact, McNeill and Krajcik (2009) showed that if scaffolds did not fade, it impeded students' independent performance on the task.

2.10.2 Discussion: Verbal Prompts as Scaffolds

Knowledge is socially constructed (Vygotsky, 1986) and class discussion helps students develop a language for talking about science including what has been learned in order to explain phenomena (NRC 2000). Students actively engage with phenomena and collaborate with each other and the teacher to make sense of ideas. Reiser and colleagues (2012) stress the importance of purposeful knowledge construction when working to figure out phenomena. They emphasize that students need meaningful engagement and meaningful interactions with peers. Verbal prompts from the teacher during class discussions and to partners as students work together in small groups can assist students towards more purposeful and meaningful interactions that allow students to delve deeper into ideas and develop stronger understanding of science ideas as part of the process of constructing explanations. In this form of scaffolding, the teacher is verbally "coaching" students and can support

[1] I was one of the participating teachers in this study and was found to successfully incorporate all four strategies. I am referred to as Ms. Nelson in these articles as well as in a book, *Supporting Grade 5-8 Students in Constructing Explanations in Science (2011)*. The book includes videotape from seven teachers. One video clip is of me introducing students to the explanation framework because it was viewed as an exemplar.

students to think more deeply by making suggestions, asking thought-provoking questions, and encouraging students to elaborate on their ideas (Krajcik & Czerniak, 2014).

2.10.3 Scaffolded Guide Sheets

Another type of support for students is teacher-prepared guide sheets. In this type of scaffolding, the coaching is done in written or pictorial form and can also serve to support students to think more deeply with written prompts and to organize their thinking. Palinscar (1998) argues that scaffolding not only occurs between people and often only through interactions between less and more experience individuals, but that the Zone of Proximal Development (Vygotsky, 1978) where students are able to complete challenging tasks with support, can occur using artifacts. ZPD's, Palinscar states, can be embedded activities in a curriculum. Guide sheets are one such artifact.

Experts have highly organized knowledge structures. Students are novices. As they begin to develop understanding of ideas, they may not yet see relationships between ideas. "Helping students to organize knowledge is as important as the knowledge itself, science knowledge organization is likely to affect students intellectual performance" (Bransford, et al., 2000, p. 177). Carefully prepared guide sheets can include prompts to assist students to think about and then articulate ideas in their writing through notes. Additionally, guide sheets can be developed to provide students with an organizing structure that serves as an outline for writing explanations. Guide sheets provide structure for the claim, evidence, and reasoning framework. Quintana and colleagues (2004) worked to develop a scaffolding guideline framework that includes areas for sense making, process management, and articulation and reflection (2004). The teacher-prepared guide sheets in this study worked, as Quintana and colleagues propose to set useful boundaries that restricted the complex task, that described the task by including an order, and facilitated the organization of the written explanation. They also include categories that prompt reflection and articulation. The guide sheets faded over time (McNeill, et al, 2006) as students gained more experience both with how to think about what their data meant as well as experience with the explanation framework as the vehicle by which to explain the phenomenon being investigated. Eventually, students should become more proficient and independent and be able to transfer these experiences to new situations.

2.10.4 Feedback

If students are to gain insight into their current level of understanding frequent feedback is essential (Bransford, et al, 2000). “Learning is enhanced by assessment that provides feedback to students about particular qualities of their work and what they can do to improve their understanding” (Pellegrino, Chedowsky, & Glaser, 2001 p. 235). Practice and feedback combined are critical to the development of skill and expertise (Pellegrino et.al 2001). Black (2003) found that student performance improved if students were provided written formative feedback with the explicit goal of helping them to see what needed to be done. The most effective teachers view themselves as coaches who understand how important it is for students to engage in deliberate practice and having a ‘coach’ who provides feedback for ways of optimizing performance (Bransford, et al., 2000, p. 177). The teacher in this study viewed herself as a coach and placed a high value on providing students with written feedback. Similar to verbal feedback provided to students as they worked in class with partners using the prepared guide sheets, written feedback provided after students constructed an explanation supported them to think more deeply by asking thought-provoking questions, assisting students to think about causal relationships, and encouraging students to elaborate on their ideas (Krajcik & Czerniak, 2014). In addition, feedback provides support related to reporting evidence, making appropriate claims, and incorporating science ideas connected to evidence when reasoning. This written feedback, and the expectation that students use the feedback to revise their explanations, facilitates students to move from novices to have more expertise both in developing integrated understanding and in the practice of writing explanations.

With various types of support from teachers including classroom discussion, guide sheets, and feedback, based on an understanding that the construction of knowledge is a social endeavor (Vygotsky, 1986), students’ written explanations can become more sophisticated, reflecting more integrated understanding. All of these supports can work together and be part of "ongoing nudging" (NRC 2007, p. 287) that encourage and support students to reflect on and articulate their ideas. Students' explanations, and thus understanding, can progressively develop over a period.

2.11 Evolving Explanation

The actual work of scientists involves a continual process of rethinking and revising explanations as new evidence comes to light. To ensure that students develop an understanding of the nature of science, a supporting document, *Nature of Science Matrix* (NGSS 2013, Appendix H) is included in the Framework. It specifies, "Scientific explanations are subject to revision and improvement in light of new evidence…. Science findings are frequently revised and/or reinterpreted based on new evidence" (p. 99). Students should regularly experience how science is actually done through engaging school experiences (NRC, 2012) and the Framework clearly articulates what students should do to accomplish this.

If we want to provide students with similar experiences as scientists then students should engage in authentic investigations where they collect and analyze data, write a scientific explanation based on all the available data, and then collect and analyze more data to see if evidence from the new data supports their original claim or to see if they need to revise their claim as new evidence emerges. This is the process that occurs in the classrooms being studied in this thesis. Based on the review of the literature, no studies were found where students write and revise one explanation over time, as new evidence emerges from the analysis of new data. The process of writing an "evolving explanation", as I will call it, places different cognitive demands on students to evaluate their current thinking, utilize their emerging understanding of the science ideas, and perhaps change their thinking that might results in altered claims. It will require a more metacognitive (Choi et al., 2011; NRC 2007) role throughout the process of investigating, analyzing, and explaining phenomena; students will need to regularly reflect on their current thinking. In such situations, students need to examine if their claim accounts for all available evidence (Duschl, 2007; Sampson & Clark, 2006), each time new data are obtained and analyzed.

Chinn and Brewer (1993, 1998) present eight responses people make to anomalous data such as students not believing the data, or questioning the validity of the data, or thinking the data to be irrelevant, among others. Students may not even detect incongruities or anomalies. However, unlike the research findings of Chinn and Brewer (1993, 1998) students may accept data as valid, but still fail to adjust their claims. They may have trouble letting go, as Brandsford and Schwartz suggest (2001), even if new evidence no longer supports those claims. Developing a curriculum that includes a process of constructing an evolving explanation as new data are collected over time, and that includes a reflective component for students to think about their current claims, more accurately mirrors what expert scientists do.

The most frequently described situations in the science education literature (Cavagnetto, 2010) where students construct multiple explanations reflect curricula where students write separate explanations throughout the curriculum based on evidence from different experiments. But what happens when new data emerges that provides additional evidence for the same phenomena? In exploring more complex systems, like the water quality of a stream that the students are working to developing integrated understanding of in this study, investigating the phenomenon may be a more lengthy process with multiple data collection episodes. In this process, students can construct one explanation, but over a period of time, with each iteration becoming progressively richer. Data are not collected all at once but over a period of time (days or weeks). Students construct an explanation based on the available evidence, incorporating science concepts as part of the explanation. As more data are collected, students incorporate these findings utilizing additional science ideas, into their existing explanation. In doing so, students also revisit earlier science ideas that provide them opportunities to expand or revise their thinking, look for patterns or cause and effect relationships, thus allowing students' science understandings to progressively build. Teacher support, through class discussion, scaffolded guide sheets, and feedback during the process, assists students towards developing more connections between science ideas, resulting in more integrated understanding. The teacher in this study incorporated these intentional strategies to support students. Feedback prompts students to consider new ideas, to expand their current thinking including making connections between ideas, and to reconsider current thinking that may be inconsistent with their data or inconsistent with what scientists believe. The process may also prompt students to adjust their claims. Furthermore, the iterative approach of an evolving explanation that includes practice and feedback has the potential to provide students with an experience that allows them to more thoughtfully analyze and incorporate new science concepts when writing about new evidence. In other words, as students collect new data about the phenomenon under study, they may need to understand different science ideas in order to make sense of that data. Writing earlier versions of the explanation may provide students with experiences and the building of knowledge structures that prepare them to more fully utilize science ideas when incorporating new evidence and new science ideas into an existing explanation as Bransford's and Schwartz's (2001) emphasize, called preparation for future learning (PFL), when thinking about transfer.

The goal of constructing one explanation over time is to assist students towards developing integrated understanding utilizing the explanation framework as the vehicle by which students can be supported to develop the rich "story" of a particular phenomenon or a system under study. The aim is to assist students to learn how to develop (construct) the richest, evidence-based science "story" to explain that phenomenon. As students develop their explanation over time, not only do they have the potential to include more science ideas, but those science ideas can become more connected allowing students to tell a richer, more sophisticated "story" about the phenomenon, thus more fully explaining the phenomenon. This places them on a trajectory to move from novices towards having more expertise (Brandsford & Schwartz, 2001).

2.12 Summary

Helping students to develop integrated understanding of science is a major goal of science education. The Framework for K-12 Science Education (2012) requires the integration of three dimensions: practice, crosscutting concepts, and disciplinary core ideas, as the methodology of instruction. Similarly, the importance of students constructing scientific explanations to explain phenomena is seen throughout science education documents. In this chapter, I reviewed the literature related to integrated understanding. This included literature related to how knowledge develops over time, and how knowledge can prepare students for future learning or transfer. The study is based on a classrooms grounded in social constructivism and this has been discussed. Three-dimensional learning (NRC 2012) was explained and discussed. The chapter also included literature related to scientific explanations including challenges for students and use of scaffolds to support students. Finally, a new facet of explanations, termed evolving explanation, was proposed as a means of assisting students to make sense of more complex phenomena.

CHAPTER 3

Research Methodology

3.1 Overview of the Chapter

This chapter provides a discussion of the general methods employed in this study. Included are the research design and research questions. The context of the study, including information about the students and the teacher, the instructional materials, and the learning environment are described. The general processes of data collection and analyses are explained, as are issues of validity, reliability, and ethical issues. The chapter concludes with a timeline for the entire process of the thesis.

3.2 Design/Procedures

This study utilized a time series research design (Creswell, 2009) where students wrote four iterations of one explanation over a six-week period as part of a semester project. All four iterations were embedded in the curriculum. With each iteration, students expanded and revised the explanation based on new data and teacher feedback. I term this explanation an "evolving explanation." The various iterations of the evolving explanation were used as the data sources for addressing the research questions. The study included an in-depth look into one teacher's instructional practices and how they worked together to foster student learning of key ideas through this scientific practice.

3.3 Research Questions

This study is concerned with supporting students to develop integrated understanding through building a more sophisticated explanation over time. To achieve this aim, the study is designed in three parts and each part has its own research questions. The research questions presented below, therefore, are organized within sections based on how they are analyzed and presented in the thesis.

Making Claims (Chapter 4)

1. How do students adjust their claim as new evidence emerges?
2. What are the patterns that students' claims progress through in the various iterations of an evolving explanation?
3. What are the challenges that students face in developing one claim over time?

Integrated Understanding – Science Ideas (Chapter 5)

4. As students engage in writing an evolving explanation, how does their understanding of appropriate science ideas develop across time?
5. How does the practice of analyzing data/evidence and writing the first two iterations of an evolving explanation allow students to transfer their learning to new situations?

Integrated Understanding – Reasoning: Connecting Science Ideas with Evidence (Chapter 6)

6. How do students connect science ideas with evidence and are students able to make more connections to evidence over time?
7. Does the process of writing the first two iterations provide students with experience to make more connections of science ideas with evidence when writing about new evidence: Is there transfer?
8. How do the levels of understanding that students possess about science ideas relate to the connections to evidence that students make over time?
9. What is the impact of students' understanding of science ideas and/or connections on their ability to adjust claims when faced with new evidence?

3.4 Context of the Study

This section provides information about the students who participated in the study and about the teacher, followed by a discussion of the instructional context that includes a description of the curriculum including 3-Dimensional Learning.

3.4.1 Participants – The Students

Sixty, 7th grade students from four different science classes in an independent middle school in a small mid-western city initially participated in the study. Thirty-one percent of students in the school self-identified as persons of color. The majority of students were from middle to upper-middle income families. Eighteen percent of the student body received need-based financial aid. Forty-five percent of the students were boys and fifty-five percent were girls. The middle school is part of a 6-12 grade school. One hundred percent of the students graduate from high school and 100% of the graduates attend college each year. Two students were dropped from the study due to long-term absences, making the overall number of participants 58 students.

In each of the results chapters, actual student work is presented from findings of the various research questions. These representative, authentic examples provide a more comprehensive picture to fully articulate the ways in which students were thinking and the various challenges students faced as they collected more water quality data and then were expected to utilize this new evidence. As well, in several examples, teacher feedback is included that allows insight into the types of feedback provided to students and also the adjustments students then made to their explanation.

3.4.2 Participant – The Teacher

I am the teacher and the researcher in this doctoral thesis. I have over 20 years of experience teaching 5-8th grade science. I earned an undergraduate degree with a double major in Broad Field Science and in Education with 7-12 grade certification, and a Master's Degree in Human Development with emphasis on pre-and early adolescence. My goal is to create a classroom culture that reflects the practices of science: inquiry through collaboration where students answer meaningful questions that investigate phenomena to develop understanding of the natural world in which they live. I was co-developer of the curriculum in this study that has evolved over 15 years. Over the years I have published several articles related to project-based science.

3.4.3 Description of the Project

3.4.3A 3-Dimensional Learning using Project-Based Science

The project-based science curriculum in this study (Novak, Gleason, Mahoney, and Krajcik, 2006) utilized 3-Dimensional Learning (NRC 2012) as the methodology for science instruction. It blended scientific core ideas, scientific practices, and crosscutting concepts as envisioned by the New Framework for K-12 Science Education (2012) and more thoroughly specified in the Next Generation of Science Standards (NGSS, 2013). Specifically, the practice of constructing *scientific explanations*, the crosscutting concept of *cause and effect*, and disciplinary core ideas that blended science ideas from *Earth and Human Activity*, and *Ecosystems: Interactions, Energy, and Dynamics* related to water quality are the focus of the research presented in this thesis. Another goal of science education is to assist students to understand the nature of science (Nature of Science Matrix, NGSS 2013, Appendix H). One component of the Nature of Science, that "Scientific Knowledge is open to Revision in Light of New Evidence" is also a focus of this dissertation. A summary of the 3-Dimensional Learning ideas in the water curriculum is presented in Figure 3.1. A more comprehensive table may be found in Appendix A. Other practices embedded in the unit that are not investigated in this study include, *Asking Questions and Defining Problems* and *Planning and Carrying Out Investigations* (Appendix F, NGSS 2012). Crosscutting concepts of *Patterns, Systems*, and *Stability and Change* (Appendix G, NGSS 2012) were also part of the curriculum, but not part of this study.

Developing a curriculum that requires students to "operate at the intersection of practice, content, and connection, is the "real innovation in the NGSS" (p. xvi) and these are translated into performance expectations. The curriculum in this study works to build towards several performance expectations that are summarized in Figure 3.2.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Practice 1: Asking Questions and Defining Problems. Practice 3: Planning and carrying out investigations *Practice 4: Analyzing and interpreting data *Practice 6: Constructing explanations *Practice 7: Engaging in argument from evidence *Practice 8: Obtaining, evaluating, and communicating information	MS-LS2 Ecosystems: Interactions, Energy, and Dynamics • LS2.A: Interdependent Relationships in Ecosystems (MS-LS2-1) (MS-LS2-2) • LS2.B: Cycle of Matter and Energy Transfer in Ecosystems (MS-LS2-3) • LS2.C: Ecosystem Dynamics, Functioning, and Resilience (MS-LS2-4) (MS-LS2-5) MS-ESS2 Earth's Systems • ESS2.C: The Roles of Water in Earth's Surface Processes (MS-WW2-4) MS-ESS3 Earth and Human Activity • ESS3.A: Natural Resources (MS-ESS3-1) • ESS3.C: Human Impacts on Earth Systems (MS-ESS3-3) (MS-ESS3-4)	1. Patterns. 2. Cause and Effect: Mechanism and explanation. 4. Systems and system models 7. Stability and change. …………………… Connections to Nature of Science** Scientific Knowledge is open to Revision in Light of New Evidence

Figure 3.1: Summary of Curriculum's 3-Dimensional Learning Ideas from the Framework/NGSS

*Related to Scientific Explanations.

**The Curriculum incorporates many more connections to Nature of Science, but only one is reported here as it represents a focus of this study.

MS-LS2: Ecosystems: Interactions, Energy, and Dynamics	**MS-ESS3: Earth and Human Activity**
Students who demonstrate understanding can: • MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations. • MS-LS-2. Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems. • MS-LS1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.	Students who demonstrate understanding can: MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems. MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment. *MS-ESS-4. Develop a model to describe the cycling of water though Earth's systems driven by energy from the sun and the force of gravity. *Performance Expectation from MS-ESS2: Earth's Systems

Figure 3.2: Performance Expectations the Water Curriculum Builds Towards (Framework/NGSS)

3.4.3B The Water Project

The curriculum, which the researcher developed[2] and taught (Novak et al., 2006) using a project-based science approach (Krajcik & Czerniak, 2014), worked to contextualize learning by creating a meaningful learning environment situated in an authentic, real world context that drove a need for learning. Working from students' everyday experiences with fresh water and with peoples' land-use practices, and investigating the water quality of a local stream, the curriculum worked to build and connect ideas across the curriculum. Students were first introduced to the water study through several contextualizing and benchmark lessons (Krajcik & Czerniak, 2014), teacher-directed activities used to introduce important science concepts, principles, or skills and that set a meaningful context. These lessons focused on general foundational science ideas related to watersheds, topography, point and non-point source pollution, needs of organisms, and population dynamics. As part of this open-ended, non-routine, long-term investigation, students were then organized into teams and assigned to one of nine sections of a stream (see Appendix B) where they

[2] The curriculum was developed in collaboration with teacher colleague Chris Gleason

collected four pieces of empirical data in real time, across four different episodes, over the course of six weeks. Prior to data collection, students engaged in benchmark lessons in class where water quality measures, including science ideas related to the causes and effects of a specific water quality test, were introduced.

These lessons included any actions by people on the land that could contribute to the causes, indirectly through run-off, or directly as point-source pollution. It also included the possible effects on freshwater organisms and the ecosystem either as a direct result of peoples' actions or as an indirect result of a land-use practice that could trigger a chain reaction of events impacting organisms in the stream. For example, students could hold a carwash on the street and soapy, basic water could run down the street and into storm drains that connect to the stream. Fish could then die because they cannot survive in basic water. Another example could be fertilizer that people put on their lawns that could be carried into a storm drain or simply run downhill during a rain event. Fertilizer contains nitrogen and phosphorous that help plants grow, causing an overabundance of these two nutrients. An algal bloom in the water could ensue and when that algae dies it provides an abundance of food for bacteria, who also need oxygen. The large food source could result in a bacteria population explosion and the excess bacteria could use up all the oxygen. The effect would be insufficient amounts of oxygen for aquatic organisms, like fish, that would eventually die. This chain reaction could be the beginning of an out-of-balance (life) cycle resulting in dead zones or oxygen depleted fresh waterways. Additionally, through experiments students learned how to use particular instrumentation needed for data collection. Next, each student then wrote a background information paper composed of defining what the test was and what the test measured, the causes or sources of the potential pollutant[3], and the potential effects to aquatic organisms. The stream was also part of a watershed that was in a northern climate with icy and snowy winters. Students also wrote predictions of outcomes based on observations during a stream walk and from their emerging understanding of science ideas.

[3] The amount of dissolved oxygen is not a pollutant. Rather, oxygen is essential for fish and other aquatic organisms. Determining the amount of dissolved oxygen is an important water quality data.

3.4.3C The Stream

Each stream section had unique features that could result in students obtaining slightly different results and/or that could have had different causes for the results (See Appendix B). For example, one section had a storm drainpipe where water drained into it from eight storm drains located at a nearby street. Another section was not at the stream, but rather was a holding pond that had a drainage pipe connected to the storm drains in the school's parking lot. The holding pond then drained into the stream at another section. Two sections had eroded stream banks. Two other sections were adjacent to condominiums that had well-manicured lawns. Despite the variety of stream sections, the water quality results, as reported by the teacher, had been fairly consistent over the years that the curriculum was enacted including the results from the data reported in this study. A similar cycle occurred for each water quality measure; students were introduced to science ideas related to a water quality measure through in-class discussion and benchmark lessons. The students wrote a background paper about these ideas, made a prediction about outcomes, and then went out to the stream with water quality partners to collect data.

3.4.3D Student Water Quality Data Collection

Students collected pH, temperature or thermal pollution data, conductivity (which measures the amount of dissolved solids like salt, nitrogen, and phosphorus), and dissolved oxygen data. National Water Quality Standards developed for freshwater lakes, rivers, and streams (Stapp, & Mitchell, 1995) were used that categorized all water quality test results, including those in this curriculum, as *excellent, good, fair,* or *poor.* If a water quality test fell into the *excellent* or *good* range for water quality standards, the stream was considered healthy for freshwater organisms with *excellent* being better than *good*. If, on the other hand, the test results matched up with *fair* or *poor* water quality, the stream had problems related to supporting freshwater organisms with *poor* being the most problematic. In addition to chemical testing, students also recorded qualitative data made from observations in and near the stream that were particular to the causes or effects of each water quality measure.

With some variability, student pH water quality data were either *excellent* or *good* meaning the pH of the stream was neutral. Results of the temperature test, which was conducted a week after the pH test, indicated that no section had thermal pollution with all student data categorized as either *excellent* or *good*. Conductivity data for all students data resulted in *poor* water quality, reflecting too many dissolved solids. Dissolved oxygen results were a mix with student data ranging across all of the water quality standards.

3.4.3E Constructing the Explanation

When students, or scientists, investigate a phenomenon they are responding to a question to explore and explain the natural world. Scientists often construct scientific explanations in order to explain phenomena. In this curriculum, students developed one explanation over time, an *evolving explanation*, to address the question, "*How healthy is our stream for freshwater organisms?"* (Novak et al,. 2006; Novak, McNeill, & Krajcik, 2009). The explanation gradually developed over the course of six weeks as more and more data were collected and analyzed to provide new evidence and as students also learned more about those science concepts related to water quality through the benchmark lessons: class activities, experiments, and background information; these ideas were then used in their explanations. In each cycle of data collection and analysis, students took part in discourse both in class discussions and in small groups with partners as well as other support from the teacher.

The explanation structure was a framework (McNeill & Krajcik, 2011) that included a claim, evidence, reasoning, and rebuttal. Students would make an initial claim about the health of the local stream based on available evidence and then adjust that claim, if needed, as more evidence was obtained. In order to *reason* about evidence students had to use science ideas: what the test was measuring, why results were obtained (causes) and what the results meant (effects or consequences) for the health of the stream, specifically the organisms that inhabited the stream. They needed to base these reasons on both quantitative and qualitative results they obtained at the stream. The rebuttal, in this instance, was used to explain why a potential cause or effect was ruled out rather than why an alternative explanation was ruled out (McNeill & Krajcik, 2011). The rebuttal is not the focus of this thesis. The goal of constructing one explanation over time was to support students towards developing integrated understanding utilizing the Explanation Framework as the vehicle by which students could be supported to develop the rich "story" of explaining the water quality by using the results of the various water quality tests. The aim was to assist students to learn how to develop (construct) the richest, possible evidence-based science "story" to explain various phenomena, in this case related to the water quality of a stream. As students developed their explanation over time, not only would they include more science ideas, but those science ideas would become more connected allowing students to tell a richer, more sophisticated "story" of the health of the stream for freshwater organisms that was the explanation of the phenomena.

After collecting two pieces of water quality data, pH and temperature, but before the introduction of the Explanation Framework, students were asked to write an initial explanation (Ex1) based on what they thought a scientist would write to answer the question, "*How healthy is the stream for freshwater organisms?*" The teacher then introduced the students to the Explanation Framework. In addition to defining explanations, presenting a rationale for developing explanations, and modeling everyday and science examples of explanations when introducing the explanation framework (McNeill et al., 2008), the teacher used three additional strategies to assist and support students. First, the teacher prepared scaffolded guide sheets that included various prompts related to making a claim, reporting quantitative and qualitative evidence, and what to incorporate into their reasoning and rebuttal that explained what the test measured, what the results meant, if the results were positive or negative for freshwater organisms and why. Students were also guided to include whether the results indicated the stream's health as *excellent, good, fair*, or *poor*, using the National Water Quality Standards (Stapp & Mitchell, 1995) that categorize all water quality tests. Students recorded notes on the guide sheets, with their partners, that they then used as an outline to construct their individual explanation. The level of detail in these guide sheets/worksheets faded in subsequent iterations as students gained more experience in writing explanations. Two examples of guide sheets may be found in Appendices C and D. Second, the teacher provided verbal prompts during class discussions. The teacher also moved from group to group to assist students as they worked together in small groups. Lastly, written teacher feedback was provided to students following the second and third iterations (Ex1 & Ex2) of the explanation to assist them to make connections, expand their thinking, rethink if needed, and to consider alternatives.

In summary, students completed an initial explanation (Ex 1) before acquiring knowledge about scientific explanations. After the introduction of the explanation framework students took notes with their partners from a teacher prepared guide sheet and used these notes as an outline to individually revise their initial explanations (Ex2). Once students completed Explanation #2 the teacher provided each student with electronic feedback. Next, students engaged in various classroom activities and did some background reading to learn about a third water quality test, conductivity, and then collected conductivity data at the stream. This third piece of data was then incorporated into their explanation (Ex3); Explanation 3 included revisions of pH and temperature, based on teacher feedback, plus conductivity evidence, reasoning and rebuttal and an adjusted claim, if warranted by the evidence. Ideas related to conductivity were generated from notes students took with their partners using a fading scaffolded guide sheet (Appendix C) and from a classroom discussion. The fourth and final explanation (Ex4) included additional teacher feedback about the first three water quality measures plus the inclusion of dissolved oxygen data that followed the same process described above.

3.5 Data Collection/Data Sources

Each of the four iterations of the evolving explanation for all students was completed as word documents and emailed to the teacher. The first iteration of the evolving explanation, *Explanation #1 (Exp.#1)*, took place after students collected pH and temperature data but prior to students' introduction to the explanation framework. These explanations provided a baseline to examine students' development in writing explanations. Teacher feedback from Explanations #2 and #3 was done electronically using track changes and then emailed back to students to be used for revision and so that students could add ideas related to the next water quality test for the next iteration of the explanation. This electronic feedback also served as a data source. Lastly, student scores from a teacher prepared end of the semester examination related to science concepts of the four water quality measures (pH, temperature, conductivity, and dissolved oxygen) were computed.

3.6 Data Analysis

This thesis explores the scientific practice of students' constructing explanations. There are several components of an explanation and this study explores, in depth, several of these components. It is designed in three parts and each has its own analysis. What is presented in this section is the general analysis that was used for all three parts of the study. Further articulation of analyses related to specific research questions is included in three separate chapters. Chapter 4 focuses on student claims; additional discussion of how data were analyzed related to claims are included in that chapter. Likewise, Chapter 5, which focuses on students' development of science ideas across the four iterations of the explanation, includes data analyses specific to that data. Finally, Chapter 6, which explores science connections students to make to evidence across the explanation, how connections and science ideas may be related, and if and how each relates to claims students make, are further articulated in that chapter.

3.6.1 General Data Analysis

A rubric, which was generated from a comprehensive concept map, was utilized to investigate each of the nine research questions for the study. The rubric included claim, evidence, and reasoning[4]. Analyses of students' claims are explored in Chapter 4. The reasoning portion of the rubric included development of science ideas and the connections of those science ideas to evidence. Chapter 5 focuses on students' development of understanding of science ideas and Chapter 6 focuses on reasoning, the connecting of those ideas to evidence. The comprehensive concept map (Appendices E, F, G, and H) (Novak & Gowin, 1984) was created by the researcher and represented all of the science ideas and the relationships and

[4] The rubric also included rebuttal and action step that are not reported in this thesis.

appropriate connections between them. Three water ecology experts evaluated this concept map for scientific accuracy verifying that it contained all the science ideas and all the relationships. Next, the concept map was used to create a detailed rubric using as a guide, a base rubric for analyzing scientific explanations (McNeill & Krajcik, 2011) that is presented in Table 3.1.

Table 3.1: General rubric for scoring explanations (McNeill & Krajcik, 2011).

Component	Level		
	0	1	2
Claim A statement that responds to the question asked or the problem posed.	Does not make a claim, or makes an inaccurate claim]	Makes an accurate but incomplete claim.	Makes an accurate and complete claim.
Evidence Scientific data used to support the claim.	Does not provide evidence, or only provides inappropriate evidence (Evidence that does not support claim).	Provides appropriate, but insufficient evidence to support claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support claim.
Reasoning Using *scientific principles* to show *why data count as evidence* to support the claim.	Does not provide reasoning, or only provides reasoning that does not link evidence to the claim.	Provides reasoning to link claim-evidence. Repeats the evidence and/or includes some scientific principles, but not sufficient.	Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.

In order to develop this rubric, science ideas and their connections from the concept map were translated into statements, one by one, and became part of the rubric. The water ecology experts also verified the rubric for scientific accuracy. The rubric then reflected accurate science ideas and meaningful connections between ideas. Figure 3.3 shows the pH portion of the concept map. Table 3.2 is the translation of those science ideas into statements that became the pH portion of the rubric.

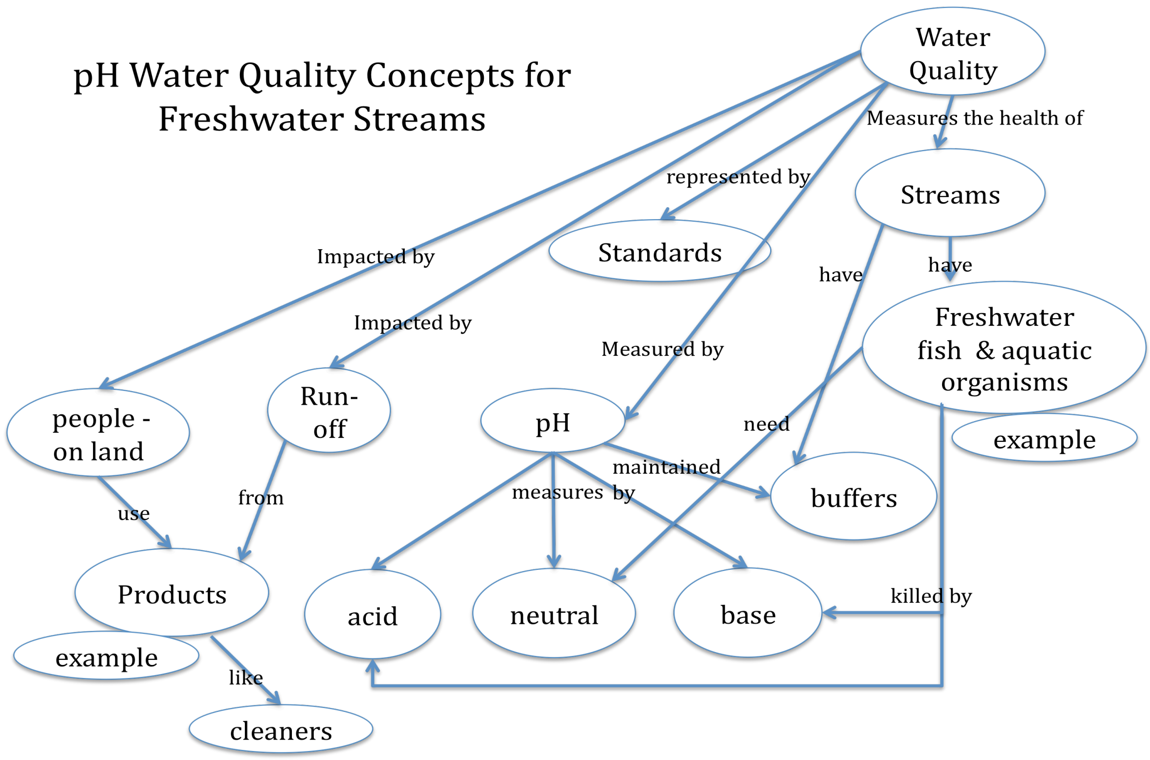

Figure 3.3: Concept Map - pH Water Quality Science Ideas

Table 3.2: Rubric for evaluation pH science ideas

Reasoning – Science ideas
__0__ Does not provide science ideas or provides inappropriate ideas.
Provides all science components: WHAT evidence means and WHY these results? pH Reasoning __1__ Stream is acidic? Basic? Neutral? correct __1__ Correct Standard –most neutral a couple slightly basic (excellent or good – a couple fair) positive results: __1__ Most organisms need neutral pH or will die __1__ Example: name of organisms and pH range needed __1__ Example - product and pH from land-use and run-off __1__ Buffers – define

Students' earned one point for each accurate idea. Ideas that were inaccurate or missing were scored as zero. As seen in the rubric (Table 3.2), the maximum number of possible points for pH science ideas was six. This same process was used for developing rubrics for temperature, conductivity, and dissolved water quality measures as well. In addition, the reasoning portion of the rubric included points for connections (or links) to evidence for each of the water quality measures. Students earned two points if there was a clear connection to evidence, one point if they made a vague connection, and zero points if they did not connect the science ideas with their evidence (discussed in detail in Chapter 6). The rubric also included the claim and evidence. Rubric #4 (Appendix I) is the comprehensive rubric that was used after students completed the final iteration of the explanation and includes ideas for pH, temperature, conductivity, and dissolved oxygen. The other rubrics included information specific to water quality measures that were part of that particular iteration of the explanation. Table 3.3 is the rubric with pH and temperature ideas that was used for Explanations #1 and #2. The same rubric was used; the only difference was Explanation #1 was written prior to students knowing about the Explanation Framework. and Explanation #2 was written after students were introduced to the framework. The possible points students could earn are included in the rubric. Sections for Claim, Evidence, and Reasoning were utilized for research in this thesis[5].

[5] Rebuttal and Action Step were part of the rubric but are not part of this study.

Table 3.3: Rubric for Explanations #1 & #2 “How Healthy is Greenhills’ Stream?” – two pieces of evidence

Claim (C)	**Evidence (E)**	**Reasoning (R)**	**Rebuttal (Re)**	**Action Step (A)**
__0__ CA. Does not make a claim or makes an inaccurate claim. __1__ CB. Makes a vague claim __2__ CC. Claim includes only one of the following: Stream’s health for organisms OR Standard or combination of standards __3__CD. Claim includes BOTH stream’s health for organisms & Standard PLUS __1__ CE. Claim emerges from 1 piece of evidence __2__ CF. Claim emerges from 2 pieces of evidence PLUS __0__ CI. pH & temp Evidence not synthesized into one claim __1__ CJ. Evidence partially synthesized	__0__ EA Does not provide evidence or only provides inappropriate evidence. Provides quantitative data and at least 2 pieces of qualitative evidence for all 4 Water quality tests & evidence supports the claim pH Evidence: __2__ EB. Quantitative (Includes numbers at all 3 locations or summarizes numbers at all locations = 2. or Only reports numbers at one location w/o referencing other locations -= 1) __2__ EC. Qualitative (ie soap bubbles, nearby sources – homes, windows, roads, etc) temperature differences: __2__ ED. Quantitative (Includes numbers at all 3 locations or summarizes numbers at all locations = 2.) Or Only reports numbers at one location w/o referencing other locations -= 1) __2__ EE. Qualitative (ie surfaces, particles, shade)	__0__ RA. Does not provide reasoning or provides inappropriate reasoning. Provides all reasoning components: WHAT evidence means and WHY these results? Connects reasoning to evidence for each WQ test. pH Reasoning- science ideas __1__ RB. stream is acidic? Basic? Neutral? correct __1__ RC. Correct Standard –most neutral a couple slightly basic (excellent or good – a couple fair) positive results: __1__ RD. Most organisms need neutral pH: will die __1__ RE. Ex: name of organisms and pH range needed __1__ RF. Ex. - product and pH from land-use run-off __1__ RG. Buffers – define Connects pH reasoning to pH evidence __0__ RH. No connection* __1__ RI. Vague connection* choose one* __2__ RJ. Clear connection* Temperature differences: science ideas __1__ RK. No thermal pollution/abnormal temp inc __1__ RL. Correct Standard – (excellent or good) Positive results: If thermal pollution: __1__ RM. fish die __1__ RN. promotes algal bloom __1__ RO. can hold less D.O., __1__ RP. sick fish	__0__ Re. Does not recognize an alternative explanation exists or make an inaccurate rebuttal Recognizes and describes at least one alternative explanation and why alternative explanation is not appropriate – one rebuttal per WQ test pH rebuttal __0__ ReA. No rebuttal or inaccurate rebuttal __1__ ReB. Attempt’s rebuttal __2__ ReC. Accurate rebuttal (ex: products from land-use run-off into stream; not occurring now or buffers working, acid rain: stream is not acidic) Temp. Difference rebuttal __0__ ReD. No rebuttal or inaccurate rebuttal __1__ ReE. Attempt’s rebuttal __2__ ReF. Accurate rebuttal (ex: no factories to dump not water, weather – too cold particles/surfaces could heat in warmer weather	__0___(AA) Does not provide action step and how that action step will help Provides one action step and discusses why that will help (something to stop doing, continue to do, or to avoid) pH action step __0__ AB No action step __1__ AC action step no reason __2__ AD action step with reason temp action step __0__ AE No action step __1__ AF action step no reason __2__ AG action step with reason

into one claim __3__ CK. Evidence synthesized into one claim	Reasons for results? __1__ RQ. Weather – too cold (November) --- → __1__ RR. particles not heating up __1__ RS. surfaces not heating up Connects Temp reasoning to temp evidence __0__ RT. No connection* __1_ RU. Vague connection* choose one* __2__ RV. Clear connection*

3.7 Validity and Reliability

Measures were taken to ensure that data analyses were both valid and reliable.

3.7.1 Validity

Three water quality experts worked with the researcher to ensure the accuracy of the science content. One was a water ecologist, another a Stewardship Coordinator, and the third a retired professor of water chemistry. All three worked for the Huron River Watershed Council in Ann Arbor. The three water ecology experts evaluated the comprehensive concept map for scientific accuracy verifying that it contained all of the science ideas and all of the relationships. They also verified the rubric for scientific accuracy.

3.7.2 Reliability

Scores were compiled for all iterations of the explanation for each water quality measure that was included. Three scorers[6] knowledgeable of the science curriculum and of the structure and use of scientific explanations in classrooms scored explanations from some of the students. These scorers each scored the four iterations of four different students totalling 16 explanations. An 88% inter-rater reliability was obtained. The first author scored the remainder of the other students' explanations. To prevent "drift" in scoring, the two other scorers scored four additional students

[6] Special thanks to Chris Gleason and Martha Friedlander for their assistance and expertise in scoring student explanations.

(16 explanations) that were set aside. Half-way and three-fourths of the way through the scoring process, the researcher chose and scored two of these students to check for consistency to prevent any drift.

3.8 Ethical Issues

Approval for the research in this thesis was obtained from the Human Research Ethics Committee (Project Number: SMEC-99-11) to collect research data from November, 2011 to November 2012. Approval established conformity with the NHMRC National Statement on Ethical Conduct in Human Research. This included gathering informed consent to participate in the research project, protection of privacy and confidentiality of records and conducting research that ensured no risk of harm to students.

The purpose of the research and the student involvement was explained to students in class and to parents in a letter. Written permission from both students and parents was obtained. Since I was both the teacher and researcher, precautions were taken to ensure that students and did not feel uncomfortable about the idea of being "studied". Students and their families were assured that all data would remain confidential and anonymous: that students and the site of the research were not to be identified in the thesis. Students had the option to participate or to decline to participate in the study. For all students in the study the artifacts were to be identical to what they would develop as part of their normal classroom experience whether they chose to participate in the study or not. The study posed no threat of risk or harm to students. Because the evolving explanations served as embedded assessment for student learning during the semester as well as for data to be analyzed at a future time, it was made clear to students and parents that, although assessment criteria in the form of rubrics were similar, two different processes would take place: one process was what normally occurred during the semester where student assessments culminated in an overall grade for school reporting purposes and the other process was analysis for the thesis. This latter process was to be confidential and anonymous.

3.9 Time Line

In the following section I summarize what was done during the various years of the PhD program related to the thesis.

Year One

A literature review was conducted during year one. In addition, the thesis proposal was written. The Application for Candidacy was approved.

Year Two

During the first semester, each of four iterations of the evolving explanation for all students was collected. Teacher feedback from Explanations #2 and #3 was also collected. In addition, student scores from an end of the semester examination related to science concepts of the four water quality measures were collected. During the second semester of this year, the data were organized.

As well as data collection and organization, a comprehensive concept map of all of the science concepts was created in year two. Rubrics were created to score student written artifacts. Two meetings were conducted with three water ecology experts. These experts evaluated the comprehensive concept map for scientific accuracy verifying that it contained all of the science ideas and all of the relationships. They also verified the rubric for scientific accuracy.

Lastly, data analysis began during the summer. Two knowledgeable individuals independently scored four student explanations for each of the four artifacts (totally 16 iterations) using the rubrics. These scores were matched with my scores to ensure reliability. Adjustments were made where necessary. In addition, the two other scorers scored four additional students (16 explanations) that were set aside. Half-way and three-fourths of the way through the scoring process (during year three), the researcher chose and scored two of these students to check for consistency to prevent any drift.

Year Three

During Year three, I continued to analyze data and expanded the literature review. I submitted a proposal and it was accepted to present a portion of my thesis data at the annual Science Association for Research in Science Teaching (NARST) conference during April of 2013. The international conference was held in Puerto Rico. I wrote a 30-page paper for this presentation. The title of my presentation was: *Adjusting Claims as New Evidence Emerges: Do Students Incorporate New Information into their Scientific Explanations?*

Year Four

I continued to analyze part of my data and began to write up part of my dissertation. I submitted a proposal to present a portion of my data at the annual Science Association for Research in Science Teaching (NARST) conference in March 30-April 2, 2014 and it was accepted. The international conference was held in Pittsburgh, PA, USA. I wrote a 25-page paper for this presentation. The title of my presentation was: *Supporting the Development of Integrated Science Understanding using an Evolving Explanation with Synergistic Scaffolds.*

I analyzed the last portion of my data. It included statistical analysis of various measures involving my entire study. I finished analyzing this data during the summer of 2014 and wrote up the rest of my thesis.

3.10 Summary

The general methods employed in this study were presented in this chapter. The research design discussed and the various research questions were stated. The context of the study was discussed. This included information about the students who participated in the study and their teacher. The instructional materials and the learning environment were described. The general processes of data collection and analyses are explained, as were issues of validity, reliability, and ethical issues. The chapter concluded with a timeline for the entire process of the thesis.

CHAPTER 4

Adjusting Claims as New Evidence Emerges: How do Students Incorporate New Information into their Scientific Explanations?

4.1 Overview of the Chapter

This chapter presents research that explores how students modify their claims over the four iterations of the evolving explanation. As new data were collected and analyzed to provide additional evidence students may need to evaluate their current claims to see if they take into account all available evidence. This chapter explores that process including the supports that the teacher provided and challenges that students faced in developing one claim over time by responding to Research Questions One, Two and Three.

4.2 Problem Statement

Science findings are often revised and/or improved when new evidence comes to light (NGSS, Appendix G, 2013). This may necessitate the rethinking of and revising of a claim. Students need opportunities to make claims based on available evidence and then use science concepts to justify why evidence supports the claim. But what happens when new evidence emerges for the same phenomena? The "claim" portion of the *claim, evidence, and reasoning* framework is viewed as the easiest part for students to include (Berland, & Reiser, 2009; McNeill & Krajcik, 2007, 2011; McNeill et al 2006). When new evidence suggests that students adjust their current thinking however, do students incorporate this new information and modify their claim? The research portion of the thesis presented in this chapter explores how students modify their claims as new data are collected and analyzed to provide additional evidence (a more thorough discussion of literature related to claims may be found in Chapter 2).

4.3 Research Questions: Claims

This chapter examines the first three research questions:

1. How do students adjust their claim as new evidence emerges?

2. What are the patterns that students' claims progress through in the various iterations of an evolving explanation?
3. What are the challenges that students face in developing one claim over time?

4.4 Data Sources and Data Collection

Claims from each of the four iterations of the evolving explanation for all students served as the data source. Teacher feedback from Explanations #2 and #3 was also collected. The first iteration of the evolving explanation, *Explanation #1 (Exp.#1)*, took place after students collected pH and temperature data but prior to students' introduction to the explanation framework. Students were asked to write what they thought a scientist would write about the health of the stream for freshwater organisms. These explanations provided a baseline to examine students' development in writing explanations, with this particular aspect of the study focusing on their claim. Students were then formally introduced to the explanation framework (McNeill & Krajcik, 2011) as well as a guide sheet that provided them with various prompts including what to include in their claims. Next, students discussed their ideas with their water quality partners while completing the guide sheet. Figure 4.1 shows portions of the teacher-prepared scaffolded guide sheet that included prompts related to the overall claim. The claim was to state if the stream was healthy or not by including a water quality standard (excellent, good, fair, or poor) and if organisms could or could not live in the stream. See Appendix C for the entire guide sheet.

Water Quality Fall Scientific Explanation- Guide Sheet
Fill in each box with notes from your data, background, and predictions. Next, use these notes to write up a complete explanation for the health of our stream so far.

Title: Stream Section __ Explanation	
Introduction – a couple of Sentences: set context	
Make a **CLAIM** How healthy? Standard? Can organisms live?	

Figure 4.1: *Guide Sheet for Explanation #2 (partial)*

The guide sheet then served as an outline to assist students to revise their initial explanation; this was the second iteration or *Explanation #2 (Exp. #2)*. The teacher then assessed each explanation and provided each student with electronic feedback that included comments related to the explanation framework, their use of the evidence to develop their claims, and the science concepts they used. Next, following various lessons related to dissolved solids, their sources and their potential impact on the stream, a third piece of evidence, conductivity, was obtained. Groups then shared and discussed their data with the entire class. The teacher suggested that students think about their current claims to see if they needed adjustment. Students next completed another guide sheet with their water quality partners that included prompts. Figure 4.2 shows portions of the guide sheet that includes prompts for students to reflect on their current claim. Notice the underlined, italicized prompt, "*Do you need to change your current claim*?" (The entire guide sheet may be found in Appendix D). This guide sheet provided more scaffolding for the claim than the original guide sheet that students' utilized to try to intentionally support students to consider all evidence and attend to the claim.

Water Quality Explanation Outline – 3 pieces of evidence

Introduction {Set the context for the study. Each test: What is it? Why is it important? *Add to your current introduction.*

Claim {Statement: Answers the question about the stream's health. Includes standard and if organisms can live or not. *Do you need to change your current claim?*

Water Quality Explanation work sheet: Conductivity (3^{rd} piece of evidence)

Introduction {
Claim {

Figure 4.2: *Guide sheet for Explanation #3*

Students were to incorporate this new evidence into their explanation and revise their explanation, including their claim, if needed. This became *Explanation #3* (Exp. #3 - it included 3 pieces of evidence). The teacher, for a second time, provided feedback. This feedback was followed by lessons on dissolved oxygen. The same cycle occurred after students collected this fourth piece of evidence, dissolved oxygen. This final iteration of the explanation included all four pieces of water quality data and thus labeled *Explanation #4 (Exp. #4)*. The entire water project lasted roughly 10 weeks with stream water quality data collection and the written artifact of the evolving explanation occurring over about a six-week period.

4.5 Data Analysis

Four rubrics were created using a base rubric for analyzing scientific explanations (McNeill & Krajcik, 2011). Three water ecology experts evaluated the rubrics for scientific accuracy. The rubric for explanation's one and two (initial Exp.#1: <u>before</u> the introduction of the explanation framework, and then the revised explanation: Exp. #2: <u>after</u> introduction to the explanation framework) included claim, evidence, reasoning and rebuttal[7] based on pH and temperature data. The subsequent rubrics included everything from the first rubric plus evidence, reasoning, and rebuttal for conductivity (which measured the amount of dissolved solids) and then dissolved oxygen (The complete rubric may be found in Appendix I).

The original claim portion of the rubrics included only four levels shown in the first column of Table 4.3. Points ranging from zero to three were assigned to claims, based on whether or not a claim was made to a complete, appropriate claim that included both a water quality standard and a statement of the stream's health to support aquatic organisms, to anything in between. In the process of scoring student explanations, however, it became apparent that writing an evolving claim was a more challenging task for students than expected. As a result, the rubric was further elaborated and columns two and three were added. This was all done to try to obtain a more comprehensive picture of how students made claims as additional evidence was obtained and what challenges students faced when making claims. Not only did this new rubric allow me to determine if claims were made or not as well as the accuracy of the claim, the rubric also allowed me to record how many of the water quality tests were reflected in the claim (Column Two) and if students were successful at synthesizing some or all of the evidence into one claim (Column

[7] A column for *action steps* was also included. It is not discussed here because it did not impact students' claims.

Three). The rubric in Table 4.1 is only a portion of the entire rubric. The complete rubric (Appendix I) includes criteria for evidence, reasoning and rebuttal.[8]

Table 4.1: *Rubric for Analyzing Claims*

Claim	**Evidence Based On**	**Level of Synthesis**
__0__ Does not make a claim or makes an inaccurate claim. __1__ Makes a vague claim	__1__ Claim utilizes 1 piece of evidence __2__ Claim utilizes 2 pieces of evidence __3__ Claim utilizes 3 pieces of evidence __4__ Claim utilizes 4 pieces of evidence	__0__ Evidence not synthesized into one claim (conductivity & D.0. not integrated w pH/Temp) __1__ Evidence partially synthesized into one claim __3__ All Evidence synthesized into one claim
__2__ Claim includes only one of the following: Stream's health for organisms OR Water Quality (WQ) Standard or combination of standards		
__3__ Claim includes BOTH stream's health for organisms & WQ Standard		

Table 4.2: *Categories: Patterns of Claims found From Students' Evolving Explanation*

1. No claim	**2. Attempted Claim**	**3. Vague claim**	**4. Partial claim**	**5. Complete claim**
Student discussed the various data but never generated a claim	• Inappropriate claim (standards didn't match evidence, standards didn't match claim) • Contradictions in the claim • Claim emerged from only one test or the claim did not reflect the new evidence • Separate claims – no synthesis	Student may have talked about the "health" of the stream but did not utilize a standard nor include anything about organisms Student only talked in very general terms	Synthesis – Student made an appropriate claim: Student adjusted the claim as new evidence emerged but only included either the water quality standard OR a statement about organisms	Synthesis – Student made an appropriate claim: Student adjusted the claim as new evidence emerged and included both a water quality standard AND a statement about organisms

[8] And *action step*.

Once explanations were scored, claims were examined to look for any commonalities among the data. As a result, various patterns emerged. From these patterns five categories were developed. The various categories are presented in Table 4.2. Based on the criteria that formed each category, each of the four iterations of a student's evolving claim was assigned to one of the categories.

Category 2, *Attempted Claim*, was further articulated for Explanations #3 and #4. This was done because the number of students with attempted claims, reflecting some type of problem illustrated by Category 2 in Table 4.2, showed such a dramatic increase from Explanation #2 to Explanation #3. Students' claims that fell into Category 2 were revisited. Patterns related to the various challenges within this group emerged. Based on these patterns, Category 2 was further elaborated into sub-categories; the sub-categories were created based on the various challenges. This elaboration was found to be useful to more fully capture the ways in which students were thinking and the various challenges students faced as they collected more water quality data and then were expected to utilize this new evidence in their claims. Table 4.3 is an elaboration of Category 2, *Claim with Problems,* from Table 4.2, into five sub-categories.

Table 4.3: *Attempted Claims – Category 2: Claims with Problems Elaborated*

2a. Ignore describes context	**2b. Ignore no context**	**2c. Separate claims**	**2d. Ignore & separate claims**	**2e. "Messy"**
1. Student sets context for all water quality tests 2. Ignores the new evidence in his/her claim 3. Claim not adjusted	1. Student does not include new water quality test in context 2. Ignores new evidence in claim 3. Claim not adjusted	1. Student makes separate claims as new evidence emerges 2. little/no synthesis 3. Compartmentalize	1. Student both ignores new evidence and make separate claims 2. Little/no synthesis 3. Compartmentalize	1. Student attempts to synthesize new evidence 2. Struggles to adjust claim 3. Claim confused/messy 4. No overall claim (for some)

It should be noted that, with the exception of Category 2e, this sequencing does not necessarily represent a development from weaker to stronger. Categories 2a through 2d simply illustrate various challenges that were identified. Student claims characterized as "messy" in Category 2e, however, do correspond to what appears to be a higher level of thinking of students. These students included all four water quality tests with one or more attempts to synthesize evidence into one claim, but they did not succeed in developing a complete and appropriate claim.

4.6 Findings: Introduction

Below I discuss the findings for each of the three research questions. For research question one, using the 5 categories presented in Table 4.2, I summarize and discuss how students adjusted their claims for each explanation. Examples of claims from actual student explanations are included. When discussing Explanations #3 and #4, I include Table 4.3, *Attempted Claims - Category 2: Claims with Problems, Expanded.* For research question two, I portray various patterns by which student's claims progressed over the course of the evolving explanation. Representative examples from student work that present the claim made in each of the four explanations are presented. These examples provide insight into how learning, relative to generating claims, developed over time. For research question three, I discuss challenges that students faced in developing one claim over time.

4.6.1: Findings for Research Question One: How do students adjust their claim as new evidence emerges?

Each iteration of the explanation is discussed to examine how students adjusted their claims. Claims from various students are provided that illustrate common examples.

4.6.1A Findings Explanation #1: Initial - <u>Before</u> introduction of the explanation framework - 2 pieces of evidence

The first iteration, *Explanation #1 (Exp.#1)*, took place after students collected pH and temperature data but prior to students' introduction to the explanation framework. Students were then asked to write what they thought a scientist would write about the health of the stream for freshwater organisms. At this point, the pH and temperature results had only been discussed separately. The results of students' claims are summarized in Figure 4.3. These are based on the various categories illustrated previously in Table 4.2.

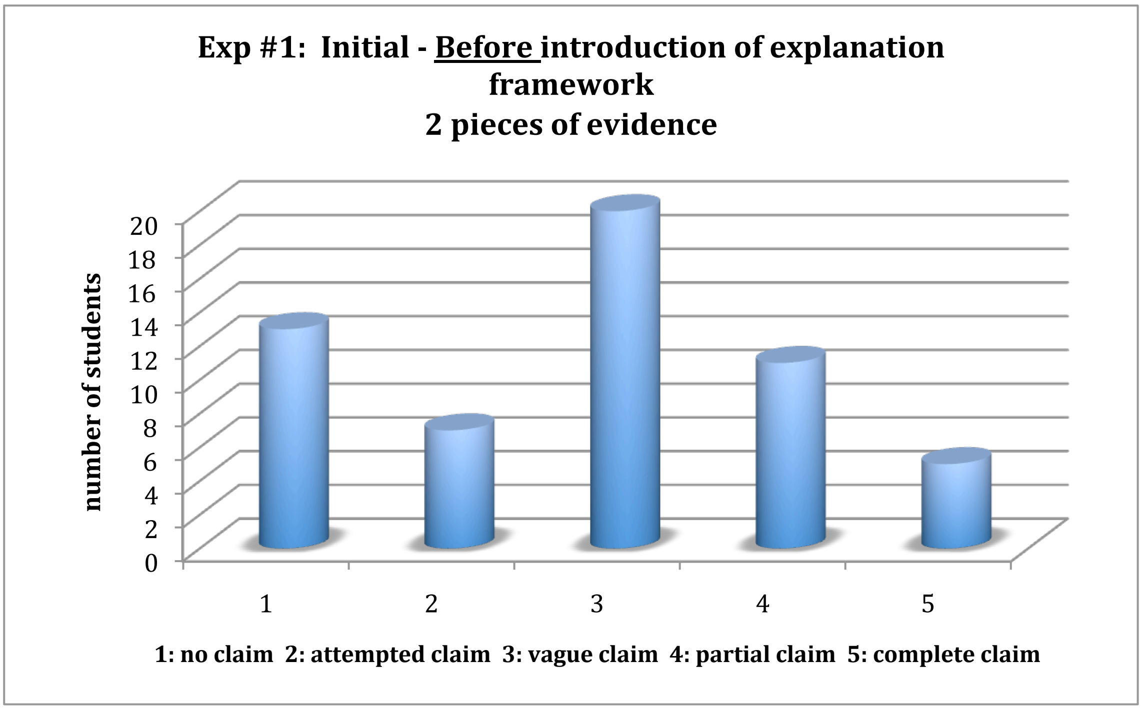

Figure 4.3: Explanation #1: Initial - Before introduction of explanation framework - 2 pieces of evidence

As shown in Figure 4.3, five students generated a complete claim. In their claims these students mirrored a format utilized by the teacher when asking students to make predictions prior to pH and temperature data collection (See Figure 4.4). This guide sheet, created by the teacher, was a subtle precursor to the explanation framework that students would be introduced to after they collected two pieces of evidence.

Guideline sheet for all Water Quality Predictions

Fall (insert test name) prediction

Use the following as a checklist:

_____ Header: Fall (insert name of test) prediction

_____ Introduction: Set the stage for the reader.

_____ Claim: Make a statement that is very specific to the water quality test. Include whether or not organisms will be able to live that is consistent with the claim.

_____Predictions for A, B and C including standards, numbers, and reasons from background knowledge.

- ____ Standards (excellent, good, fair or poor?)
- ____ Specific numbers (or small ranges)?
- ____ Reasons from Background Knowledge?
- ____ Reasons from observations at the stream.

_____ Conclusion

Figure 4.4: *Guide Sheet for Making Predictions*

Below we see Maddy's response, which is an example of a complete claim:

> *"According to the data that we have collected over the last two weeks, our stream is suitable for aquatic organisms. I have two pieces of data that clearly show that our stream is in good condition."*

She includes a water quality standard (good) as well as a statement about organisms.

In addition, 11 other students made partial claims. These were appropriate claims as well; however, they were missing either a water quality standard or a statement about organisms. Jeff wrote a partial claim that included a standard but says nothing about organisms:

> *"I believe that the section one is healthy because everything that we have tested so far has shown that the pH and temperature are good."*

Thirty-four percent of students generated vague claims in their initial attempts (20/58 students). This is not surprising, as the explanation framework had not yet been introduced to students. Most of these claims simply stated whether or not the student thought the stream was healthy. Below is Jing's claim:

> *"Based on the info we have our stream is healthy."*

Seven students attempted claims but each claim was problematic – anywhere from making an incorrect claim to developing a claim that emerged from only one of the water quality tests to presenting separate claims for pH and temperature. The claim was not an appropriate claim, based on the available evidence. Kevin's claim is an example; a stream cannot be good and poor at the same time. And if it's poor, it is not healthy. It should be noted that Kevin's pH data ranged from good to fair numbers.

> *" Scientist might think that our stream section 9 is in the good to poor range and is somewhat healthy."*

Finally, over 20% of students did not include any claim at all. Student responses ranged from simply saying that scientists collect various data, to reporting that two water quality tests were done and then sharing results. Again, since students were not familiar with scientific explanations, these results were expected.

4.6.1B Findings Explanation #2: After introduction of the explanation framework - 2 pieces of evidence

Figure 4.5 illustrates results from students' explanations before and after the introduction of the explanation framework based on two pieces of evidence.

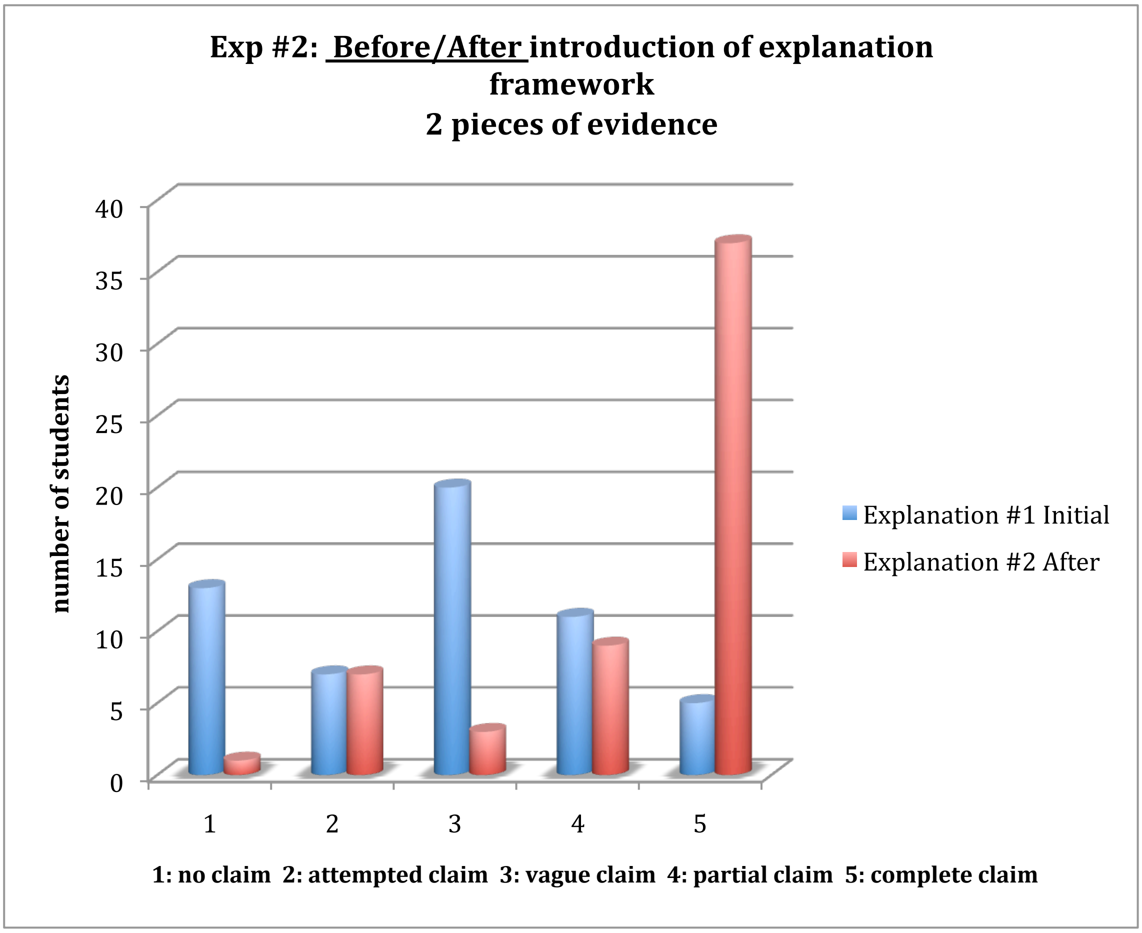

Figure 4.5: Explanations #1 and #2 Claims: Before and After the introduction of the Explanation Framework.

Most students were able to create a complete claim: one claim that synthesized two pieces of evidence (pH and temperature). Mary and Mike are two examples of students with complete claims:

> Mary*: "Section 1 of our stream is in-between good and excellent in pH testing and thermal pollution. This means organisms are able to live here."*

> Mike*: "I think the stream is healthy with test results in the good range. Good is able to support organisms so there will be life in the stream."*

Overall, both pH and temperature evidence showed high water quality. Since both water quality tests were positive the outcome most likely made it easier for students to write claims, as all available evidence indicated excellent or good water quality.

Some students wrote partial, but appropriate claims that were missing one of the criteria. For example, Bharath included a water quality standard, but did not include a statement about organisms:

> *"This paper is about us testing thermal pollution and pH in section 4 our stream. I think our stream is on the borderline between good and excellent, but more on the excellent side."*

Combining both groups, complete and partial claims, 80% of students wrote appropriate claims, based on two pieces of evidence once after they were introduced to the explanation framework.

A small portion of students (3) wrote vague claims. Below is a vague claim from Justin:

> *"In conclusion, this shows that for pH and temperature difference it shows that our stream is very healthy and were keeping it healthy."*

Several students (7) attempted claims but had problems. They wrote separate claims for each water quality test showing no synthesis of the two water quality tests. Erica was one such student:

> *"Section 8 of the stream's pH is fairly healthy and can support a few organisms."*....(later in the explanation)…*"Section 8 temperature difference is good and safe for organisms."*

Erica wrote a claim about pH followed by her evidence and reasoning. Next she wrote a claim about temperature, followed by her evidence and reasoning. In other words, she had two separate claims and did not synthesize them into one claim.

Only one student did not include a claim at all, down from the 13 students with no claims for Explanation #1.

Students received electronic feedback about their explanations from the teacher, including claims, which they were to incorporate into the next iteration of their explanation.

4.6.1C Findings Explanation #3: Incorporating new evidence - three pieces of evidence

Students experienced challenges in adjusting claims when they needed to integrate new evidence after collecting a third piece of evidence. The third water quality test, conductivity, reflected poor water quality. Now students needed to reflect on three pieces of evidence, two of which were excellent or good, and a third piece of evidence that was poor. Based on all three pieces of evidence students were to re-write their claims if warranted by the evidence. Prompts were included in a teacher prepared guide sheet (See Figure 4.2), cuing students to think about their current claims in light of new evidence. Students were also verbally directed by the teacher to reflect and decide if current claims needed to be adjusted.

In addition, the relative weight of each test was discussed. A scientist with expertise in water quality was contacted to inquire whether or not pH, temperature, (both of which had positive results) and conductivity (which had poor results for most groups) carried equal weight. The scientist reported that high conductivity does, in fact, reduce the quality of freshwater streams for organisms, but that organisms could survive is less-than-ideal conditions for this water quality test. High and low pH and high temperature differences, as well as low dissolved oxygen levels, were water quality values that could directly kill organisms. Conductivity levels related to excess nitrogen and phosphorous could indirectly kill organisms because they could lead to dead zones. Organisms could survive in water with moderate salt levels (the steam was in a northern climate were salt was used for roads during the winter), but there was a tipping point that would make the environment unsuitable for freshwater organisms.

As can be seen in Figure 4.6 the task of incorporating new evidence to adjust claims proved to be a challenge for many students. The number of students making complete claims on the second iteration of the explanation (labeled as 5 on the xaxis) was now cut in half in Explanation #3. The number of students whose claims had problems more than quadrupled. Still, others were able to incorporate this new evidence and synthesize it into one claim. Raj's claim illustrates a complete claim:

> *"I think that the stream is in the Good range of water quality standards. Organisms will be able to live there, even though one of the tests was in the Poor range of water quality standards."*

Cindy also was able to incorporate the new evidence into her claim. However, she forgot to include a statement about organisms so her claim was scored as a partial claim:

> *"I thought the water quality of our stream was excellent after testing pH and temperature difference. After we tested conductivity, I think the water quality of our stream dropped to good."*

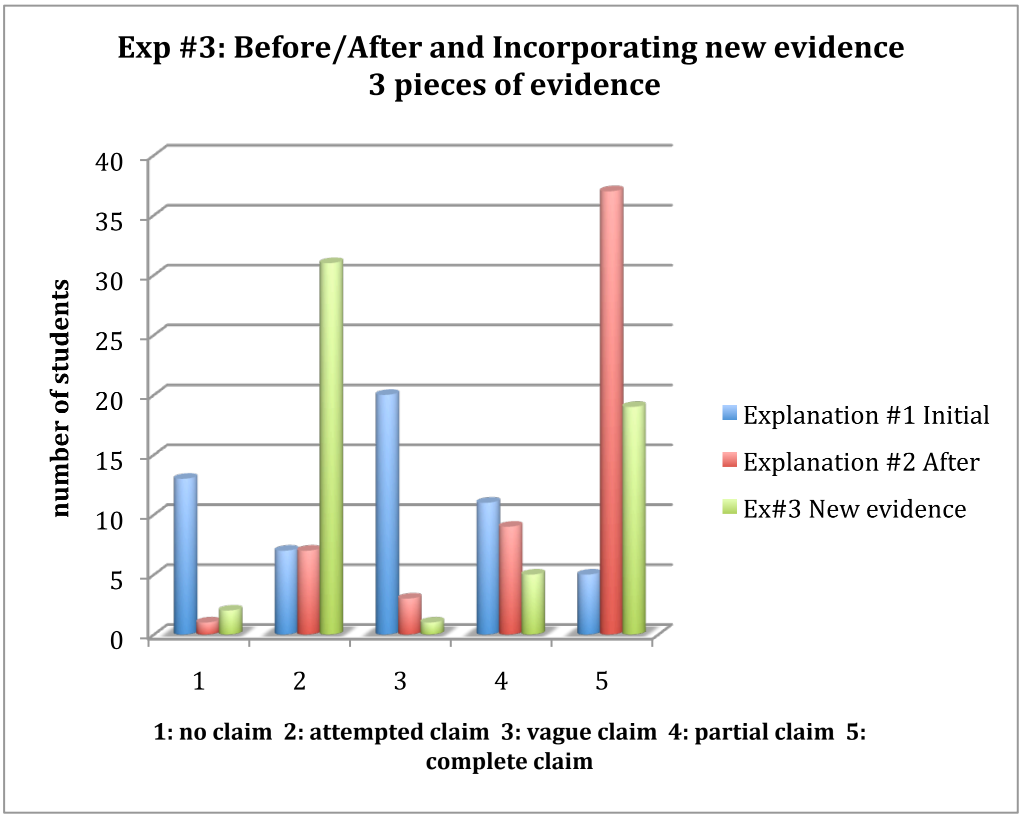

Figure 4.6: Explanation #3 Claims: New evidence – three pieces of evidence

Figure 4.7, below, illustrates the further elaboration of Category 2, students who attempted to make claims but who experienced a range of problems.

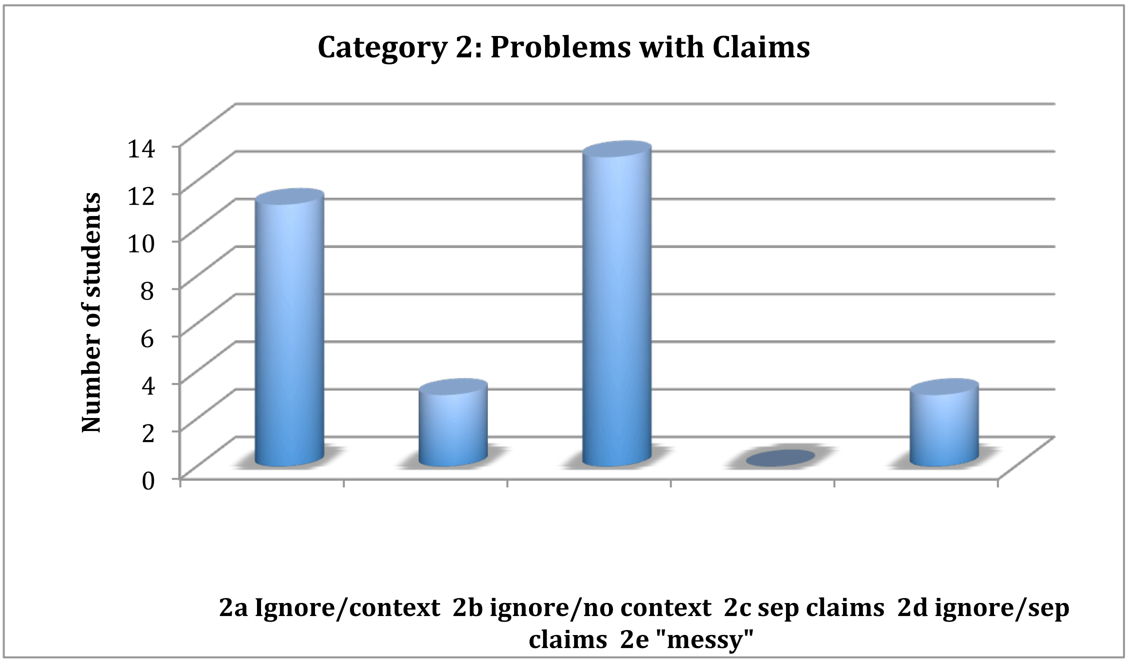

Figure 4.7: Attempted Claims Graph – Category 2 Expanded

Refer back to Table 4.3 for a more complete description of the various categories.

Naveen is an example of a student whose explanation is "messy" (2e). He is attempting to synthesize his evidence into one claim but struggles with the various pieces of evidence and how to make sense of them. Not only does he make several claims throughout his explanation, which illustrate his lack of clarity, but his claims also reflect some contradictions, which provide insights that suggest he is confused. Naveen's claim:

> *"I think that our stream, and stream section is good, with almost all our tests falling into the excellent and good range, except our conductivity test. This result fell into the poor range, which means that not all animals will be able to live there, but I think that most water organisms will be able to live here….*(later in his explanation)*… We think that not a lot of organisms will be able to live here, and that the overall health of the stream is still in the good range, but close to fair…*(at the end of his explanation)*…In conclusion,*

> *I think that the stream's health is good and according to the tests so far, it supports our claim."*

While Naveen's claim suggests he was attempting to synthesize new evidence into his overall claim, Terrell's approach (2c) to new evidence is to simply make separate claims:

> *"We claim that the pH of our stream is excellent and the temperature change is good so it has no thermal pollution or bad pH levels so it is suitable for organisms to live in….*(later in his explanation)*...Since we got negative results this means that organisms cannot survive in the water…*(at the end of the explanation)*..Now that we have taken our conductivity test we know that the stream is not healthy."*

Terrell does not attend to the task of making one claim about the health of the stream. Rather, he compartmentalizes various pieces of evidence as though he is referring to two different streams, even though he personalizes his writing using phrases like "our stream" and "our conductivity test".

Carlos' claim from his third explanation is an example of students who set no context for a third test and completely ignored the new evidence in his claim (2b) even though he discussed conductivity later in his explanation:

> *"Our stream has a healthy pH and temperature difference. And is going to be healthy enough so that organisms will be able to live in without dying or getting sick."*

Finally, Emma describes the context for all three tests (2a), suggesting that she is thinking about all three pieces of evidence, than completely ignores the new evidence in her claim:

> *"In this paper I will explain the health of the stream based on our knowledge thus far. This knowledge consists of the results from pH, temperature difference, and conductivity tests….The stream's health based on pH and temperature difference is excellent, meaning most organisms can live in it."*

4.6.1D Findings Explanation #4: Incorporating new evidence - 4 pieces of evidence

The final task for students was a 4th iteration of the evolving explanation once data from the last water quality test, dissolved oxygen, was collected. This final explanation addressed the question, *"How healthy is our stream for freshwater organisms?"* Figure 4.8 summarizes the results.

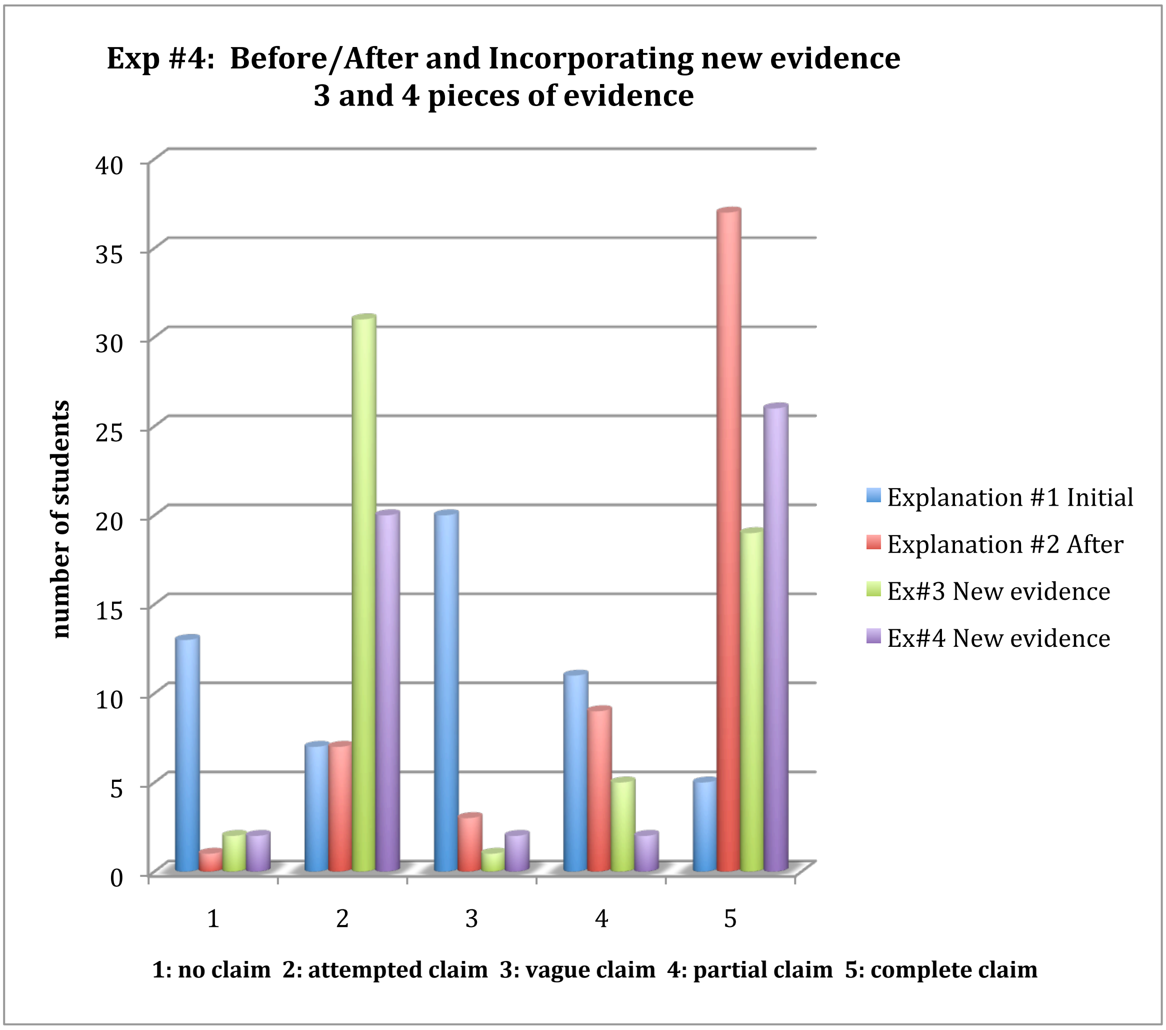

Figure 4.8: Explanation #4: Claims New evidence – Before/After, 3 and 4 Pieces of Evidence.[9]

[9] Four students did not successfully complete the final explanation. They would be added to category #2: Attempted claims with problems, increasing that number to 23 students.

Figure 4.8 shows that the number of students who were able to develop complete claims increased from Explanation #3, although the numbers were not as high as the number of complete claims made with only two pieces of evidence. Most groups determined that the final water quality measure, dissolved oxygen, was either excellent or good, meaning that there was enough oxygen to for fish and other aquatic organisms. A few groups' results were more mixed depending on their location. Examples of student claims are shown below. Tommy's claim is a complete claim:

> *"After conducting these experiments I think that the stream has good water quality and a fair amount of organisms will be able to survive in the stream. We have had great results on three of our four tests with only one test not going so well."*

Just as in Explanation #3, some students' claims in Explanation #4 reflected a range of problems. However, the number of students who had problems with their claims decreased by a third. These results are illustrated in Figure 4.9.

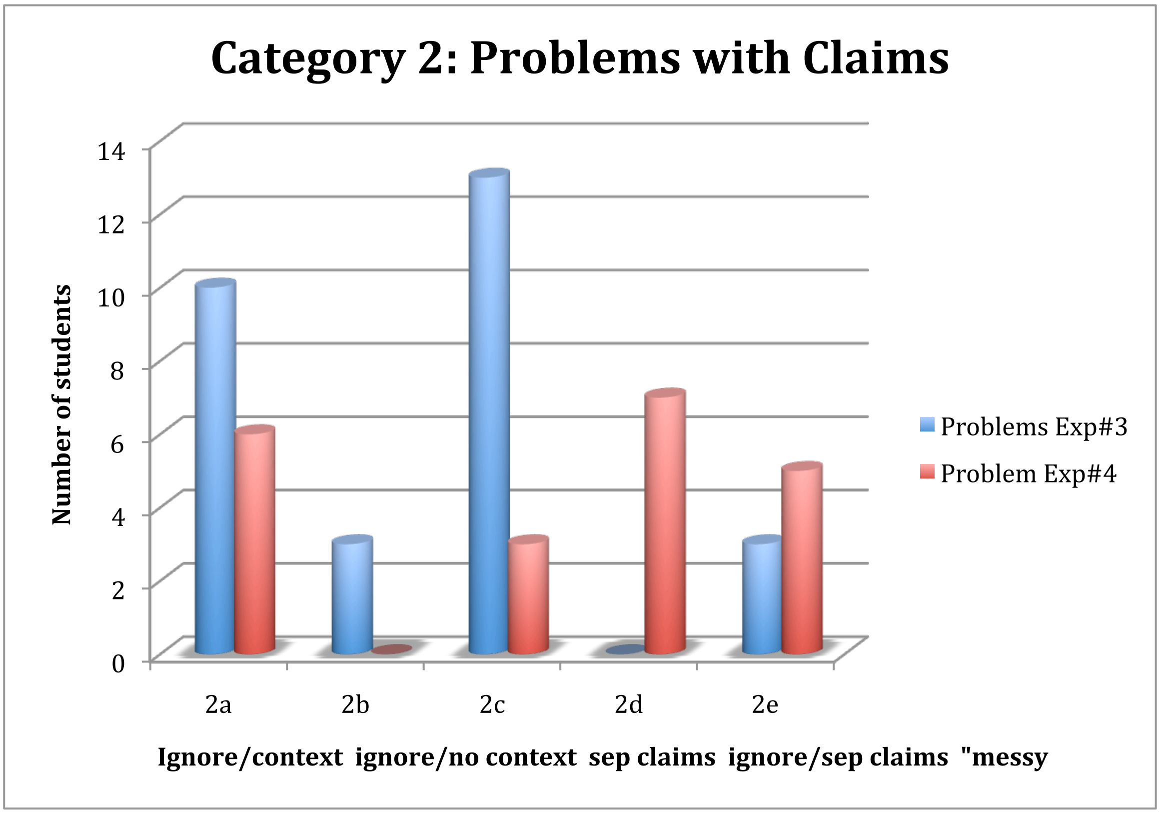

Figure 4.9: Problem Claims – Explanations #3 & #4 Category 2 Expanded

Carly's final claim is "messy" (2e). After setting a context for all four tests, she attempts to synthesize her evidence, unsuccessfully tries to make an overall claim, and ends up listing information for each test:

> *"I think that organisms can live in section 9, and the standard will be good and excellent…*(at the end of the paper*)….Overall section 9 is excellent, good, and poor state for conductivity, in the neutral zone for pH, in the excellent, good, and fair range for D.O. (*dissolved oxygen*) and in an excellent state for temperature."*

Jack's paper shows several claims that are not connected. His claim falls in Category 2c: Student makes separate claims as new evidence emerges with little/no synthesis. Compartmentalize.

> *"I now say the pH and the temperature of the stream are both excellent and can easily support life….Based on the conductivity measures at our stream, our stream is poor in conductivity….*(based on dissolved oxygen*)…The results were two good spots and one fair spot. This can support life, but not a lot of it….(*at the end of the explanation*)… In conclusion, our stream is very healthy all around."*

Jenna sets a context for all four tests and then completely ignores dissolved oxygen in her claim.

> *"Our stream is between excellent and good in the water quality standards when it comes to pH and thermal pollution but when it comes to conductivity our stream is poor this means that many organisms could easily thrive in the streams' mostly healthy atmosphere."*

It should be noted that Jenna's claim, "*many organisms could easily thrive*" exactly matched her claim from Explanation #3. In that claim, she did not take into account her poor conductivity results, even though she stated that conductivity was poor in the first part of her claim. She was thinking about conductivity but was not able to incorporate the meaning of the results (they were poor, she reported that they were poor, yet she didn't adjust her claim).

Students received electronic feedback from the teacher on their third iteration of the explanation, including reminders to incorporate evidence from the fourth water quality test into their claims. Some students effectively incorporated this feedback, along with the fourth piece of evidence, and others did not.

4.6.2 Findings for Research Question Two: What are the patterns that students' claims progress through in the various iterations of an evolving explanation?

Over the course of several weeks, students wrote an explanation as new data was collected that provided them with additional evidence to explore the question, *"How healthy is our stream for freshwater organisms?"* Students needed to adjust their claims in each iteration of the explanation as new evidence emerged. A summary graph of the claims for the four sequential explanations is below in Figure 4.10. The far right column, Category, is a reminder of the five categories identified in Table 4.2: 1) no claim, 2) attempted claim with various problems, 3) vague claim, 4) partial claim, and 5) complete claim. Both partial and complete claims reflect student claims that were accurate and synthesized. Four students were not able to successfully complete the final iteration.

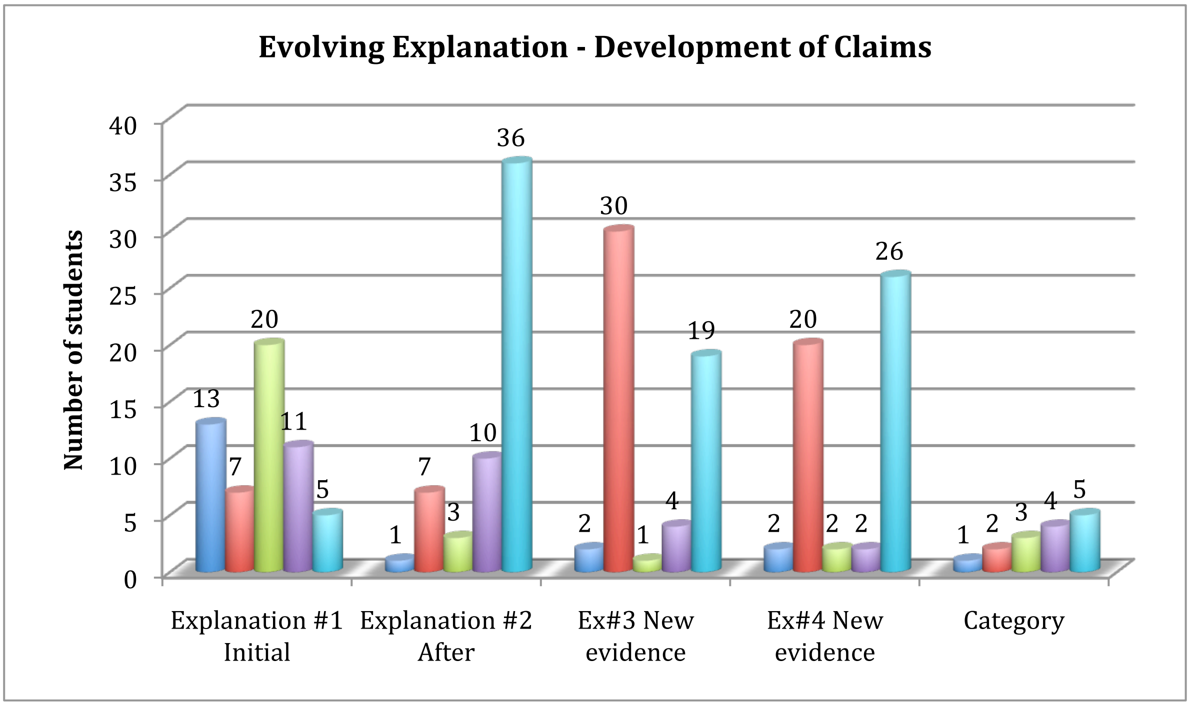

Figure 4.10: Progression of Claims in an Evolving Explanation

Students started at different points in their ability to develop claims based on two pieces of evidence. As more and more evidence emerged students' work reflected various patterns.

To answer research question two that looks at patterns, I developed several categories that emerged from student work. I first provide a summary of the major patterns that students' claims took over the four iterations. Next, I present examples of these patterns from actual student work that looks at the sequence of claims from these students throughout the four iterations of their explanation. At times, teacher feedback to students is included. The score the student received based on the categories in Figures 4.4 and 4.5 is included at the end of the claim. Table 4.4 summarizes the major patterns that students' claims took over the four iterations.

Table 4.4: *Patterns of Claims in the Evolving Explanation*

Pattern	**Description**
Direct – straight and narrow	Claims begin across all categories (1-5) prior to the introduction of the explanation framework followed by synthesized, complete claims (5) for Explanations #2, #3, and #4. (Carla)
Wandering – a bit off the path	No claims (1) or vague claims (3) initially followed by minor back and forth movement between partial (4) or complete (5) synthesized claims for Explanations #2 and #3. Synthesized, complete claims (5's) for Exp. #4. (Katherine)
Sawtooth – up and down then up	No claims (1), vague claims (3) or synthesized, complete claims (5) prior to introduction of the explanation framework followed by partial (4) or complete (5) synthesized claim for Explanation #2. Problem claims (2) in Explanation #3, followed by synthesized complete claims (5) for all but one with synthesized partial claim (4) in Explanation #4. (Mary)
Lost than Found	Problem claims (2) for Explanations #1, #2, and #3. Synthesized complete (5) or synthesized partial claims (4) for Explanation #4. (Erica)
Lost, found, then lost	Problems claims (2) prior to the introduction of the framework followed by complete (5) or partially (4) synthesized claim for Explanation #2. Problem claims (2) in Explanations #3 and #4. (John)
Going well then fell apart	Initial claims complete or partial synthesis (4 or 5), followed by complete synthesized claims (5) for Explanations #2 and #3. Problem with claims (2) in Explanation #4. One student's pattern: 5, 5, 2, and 2. (Paul and Mike)
Lost from beginning to end	All four iterations of the explanation with categories ranging from 1-3. None able to make either a partially or completely synthesized claims throughout. (Ellen)

4.6.2A Pattern: Direct, Straight and Narrow - Carla

Once introduced to the explanation framework, Carla's claims followed a direct, straight pattern. She began with a vague claim and thoughtfully adjusted her claim in Explanation #2 after the introduction of the explanation framework. She was able to integrate new evidence into synthesized claims in Explanations #3 and #4:

> <u>Explanation #1</u>: *"The Greenhill's stream in my opinion is fairly healthy."* (3)
>
> <u>Explanation #2</u>: *"The stream's health is between excellent and good this means many varieties of organisms can live there."* (5)

Explanation #3. *"The streams health is between good and fair which means some organisms can live in this environment but it is not an ideal habitat."* (5).

Explanation #4: "*The stream's health is in the good range of water quality standard which means it is a healthy environment where large variety of organisms survive.....Based off of pH and temperature the stream would be between excellent and good, but because of the results of conductivity the stream would have been in the good to fair range. Finally, based off of dissolved oxygen, pH, temperature, and conductivity the stream is in the good range."* (5)

4.6.2B Pattern: Wandering – a bit off the path - Katherine

Katherine's evolving explanation is an example of a student whose pattern followed a fairly direct route to a complete claim once she is introduced to the explanation framework. However, her claims wandered a bit, oscillating between partially and completely synthesized claims. She began with no claim, and then thoughtfully adjusted her claim in Explanation #2 after the introduction of the explanation framework. Explanations #3 and #4 show how she was able to consider new evidence, reflect on it, and incorporate it into a synthesized claim. She neglected to include a statement about organisms in her 3rd explanation so was scored with a 4 (partial) rather than a 5 (complete).

Explanation #1: *"The stream is split up into sections. My group and I chose a section and that was the section we had to do our tests on throughout the year. So far we have tested for pH and temperature."* (1)

Explanation #2: *"The stream is healthy, and the water quality is excellent. This means organisms can live here."*(5)

Explanation #3: *At first, I thought the stream was healthy, and the water quality is excellent. Now, after testing conductivity, I have changed my mind* *and now I believe the water quality is good because I think conductivity is less significant.* (4)

Explanation #4: *At first, I thought the stream was healthy, and the water quality was excellent. After testing conductivity, I changed my mind and I believed the water quality was good because I thought conductivity was less significant. However, after testing dissolved oxygen I think the water quality has dropped to fair because the dissolve oxygen percentages were so low except for one of them, at location C. Overall, I don't think organisms would be able to live in our stream because the water quality is fair.* (5)

4.6.2C Pattern: Lost, found, then lost - John

John's first explanation is also missing a claim. His pattern though, is much different than Katherine's.

Explanation #1: *"I have been assigned to a section of a stream to see how healthy it is."* (1)

Explanation #2: *"I think stream section number 4 is in excellent condition*. (4)

Explanation #3: *I think stream section number 4 is in excellent condition and animals will be able to survive.....* (towards the end)…*The stream is actually quite healthy. All in all section 4 of the stream is very healthy. Organisms will be able to live….(at the end) I think that organisms will die because the conductivity is way too high."* (2c).

Explanation #4: *I think stream section number 4 is in excellent condition and animals will be able to survive.* (2a)

John's Explanation #2 was relatively strong; it is a clear and appropriate claim about the health of the stream and a vast improvement from his first explanation that included no claim. He was only missing a statement about organisms. He received the following feedback from the teacher:

> *"Good start on the claim, but you need to say whether or not organisms can live in it or not."* (teacher feedback)

He adjusted this part of his claim in his next explanation (#3), but he was not successful at incorporating new evidence, poor results from the conductivity test, into his claim. Here is the feedback that John received from the teacher:

> *"I disagree with your claim – is it based on pH, temp diff, and conductivity? Or did you forget to modify it after our conductivity test? At the end of your paper you say you think organisms will die – b/c of high conductivity – make sure you have ONE complete and connected paper."* (teacher feedback)

The same pattern continued with the fourth piece of evidence. John did not incorporate feedback from the teacher. His claim did not take into account oxygen or conductivity evidence; he completely ignored them. His claim reflected only pH and temperature data. Overall, John's pattern reflects a student who started out "lost" then improved in his next claim and was "found" and then was "lost" in his subsequent claims.

4.6.2D Pattern: Sawtooth – up and down then up - Mary

Mary's pattern looks like a saw tooth: she began with a vague claim, had some ups and downs and then finished with a complete claim.

> <u>Explanation #1</u>: *"Is our stream healthy? Focusing on section 1, I would say yes."* (3)

> <u>Explanation #2</u>: *"Section 1 of our stream is in-between good and excellent in pH testing and thermal pollution. This means organisms are able to live here.* (5)

Explanation #3.*" Section 1 of our stream is in-between good and excellent in pH testing, thermal pollution and conductivity. This means organisms are able to live here* (2a).

Explanation #4: "*Section 1 of our stream is in the lower good range based on pH testing, thermal pollution, conductivity and dissolved oxygen. Organisms have a chance of living there but with some of the standards it will be hard to."* (5)

Mary adjusted her initial vague claim to be a complete claim in Explanation 2. Then in her 3rd iteration, she simply added the word "conductivity" but left everything else the same; she did not adjust her claim, completely ignoring conductivity evidence, but clearly thinking about conductivity. The teacher provided Mary with the following feedback:

"Claim – good. ex/good even though conductivity was so poor?!!" (teacher feedback)

The teacher first let Mary know that she recognized a claim was made ("good") and then prompted her to think more deeply about her claim to evaluate its' plausibility. Mary incorporated this teacher feedback and also attended to all of her available evidence in her final iteration, Explanation #4, and developed a thoughtful, complete claim.

4.6.2E Pattern: Lost than Found - Erica

Erica struggled with synthesizing evidence throughout the process and finally is able to produce a complete claim for the final explanation. Her pattern is an illustration of students who claims were "lost" and then "found" only by the final iteration of the explanation.

Explanation #1: *"I think our stream is fairly healthy. Our pH ranges from excellent to fair"* (2)

Explanation #2: *"Section 8 of the stream's pH is fairly healthy and can support a few organisms..*(evidence and reasoning about pH and then to introduce the next paragraph)..*Section 8 temperature difference is good and safe for organisms*. (2)

Explanation #3.*"Section 8 of the stream's pH is fairly healthy and can support a few organisms while its temperature difference is good according to standards and safe for organisms, but when we add our conductivity data, the streams health overall falls into the fair range.* (2a).

Explanation #4: "*Here are our results for all four tests. Section 8 of the stream can support quite a few organisms and the stream's health falls into the good range."* (5)

In Explanation #2, Erica compartmentalized the two water quality tests and made separate statements about them. She continued with this a little in Explanation #3. However, it appears that she attempted to bring them all together with a "fair" rating, but she neglected to make a statement about organisms within this "fair" rating. Her thinking evolved, along with her claim, and in Explanation #4, Erica developed an appropriate, complete claim that took into account all of the available evidence.

4.6.2F Pattern: Combination of Sawtooth and Lost and found - Tyrone

Tyrone started out in the process with a solid claim but then struggled to integrate his evidence by consistently compartmentalizing his evidence into separate claims. His pattern is a combination of saw tooth and lost and found:

Explanation #1: *"If a scientist asks how is section 4 doing I would say excellent."* (4)

Explanation #2: *"My stream section is in the good to excellent range in ph. Based on the data of the ph we say most organisms can live there. (a few* *sentences about pH). I claim that the temperature is excellent…… Most organisms can live there.* (2c)

Explanation #3.*"I claim that the pH for section 4 is excellent or good and that the temp is excellent. I claim that it's healthy and organisms can live there……(two paragraphs later)..I claim that the temperature is excellent…. (two paragraphs later)…I claim that the stream has conductive pollution."* (2c).

Explanation #4: "*I claim that our stream will be in the good to excellent range. I claim that pH for section 4 is excellent and that the temp is excellent the conductivity will be poor and the dissolved oxygen will be excellent. The section will be healthy and most organisms can live in it…(at the end of the explanation)….Just to recap I claim that our stream will be in the good to excellent range it will be a healthy stream and most organisms can live in it...... I claimed that our stream will be in the good to excellent range it will be a healthy stream and most organisms can live in it."* (5)

Below is feedback that the teacher provided to Tyrone after Explanation #3:

"*Claim – it includes pH and temp. What about conductivity? This paper is on all three so you claim includes all 3. Your revision will also include D.O."*

Tyrone's final claim, while a little bit "messy" and which might earn it a score, 2e, is scored as a complete claim (5) because he presented an overall claim that included all four pieces of evidence, tied everything together and included a statement about organisms. He clearly worked to synthesize the evidence and his claims evolved over the course of the various iterations.

4.6.2G Pattern: Lost from beginning to end - Ellen

Ellen is another student who struggled throughout the evolving explanation. Unlike Tyrone however, in the end Ellen was not able to synthesize all of the evidence into once claim. She took an average of all the tests at the end of the claim in Explanations #3 and #4, but this was preceded with different claims about the health of the stream based on individual tests. Ellen's claims illustrated confusion and lack of clarity all through, but with attempts toward synthesis.

> <u>Explanation #1</u>: *"In section three in the Greenhills stream my idea is that compared to other streams there is no thermal pollution with in the stream."* (1)

> <u>Explanation #2</u>: *"The stream is healthy because the pH is in the excellent and good range. This means most organisms will be able to live and survive in the Greenhill's stream. The stream is also healthy because section three compared to section eight there is a small temperature difference. This means there is no thermal pollution and the stream has an excellent to good thermal pollution.* (2c)

> <u>Explanation #3</u>.*"The stream is healthy because the pH is in the excellent range. This means most organisms will be able to live and survive in the Greenhill's stream. The stream is also healthy because section three compared to section eight there is a small temperature difference. This means there is no thermal pollution and the stream has an excellent temperature increase between the stream sections. Then when we tested for dissolved solids we got a number in the poor range. This shows now taking the average that our stream is in the low good or fair range for all three tests.* (2e).

> <u>Explanation #4</u>: "*The stream is in good condition based on the four test we have taken. The stream is healthy pH wise because the pH is in the excellent range. This means most organisms will be able to live and survive in the Greenhill's stream. When we tested for a temperature difference we got an excellent temperature increase between the sections. This means there is no thermal pollution in the stream. Then when we tested for dissolved solids we got a number in the poor range. This means there are dissolved solids in the stream. The last test we tested was dissolved oxygen. We got good, fair, and*

excellent. This shows the average of our stream is in the fair or good range because of all the tests we've taken. (2d)

Ellen presented separate contradictory claims in Explanation #3. She began saying the stream was healthy and ended saying the stream was low good to fair; these are inconsistent statements. She's clearly trying to synthesize these ideas by taking "the average of our stream". She followed a similar pattern in Explanation #4, beginning with overall claim of "good" and ending with an overall claim "in the fair or good range." Ellen and students like her were in various ways lost from beginning to end.

4.6.2H Pattern: Going well then fell apart – Paul and Mike

The final two examples are from Paul and Mike, who were only two of five students whose initial claims scored as complete, synthesized explanations. Their claims started very strong but, in the end, fell apart. For Paul, both Explanations #1 and #2 were complete. Once the third piece of evidence was introduced, Paul was not able to integrate this new evidence into a synthesized claim; he made separate claims. The same was true when the 4th piece of evidence was collected.

Explanation #1: *"I so far think our stream is healthy. I also think it can support life and all organisms. We have gotten good results from our two tests which have all been in the excellent and good range of water quality standards."* (5)

Explanation #2: *"Based upon our results our stream section is in the good range and can support organisms that live in this area."* (5)

Explanation #3*." Based upon our results our stream section is in the good range and can support organisms that live in this area. Conductivity, although, says it is in the poor range and is harder to support life."* (2c).

Explanation #4: "*Based upon our results our stream section is in the good range and can support organisms that live in this area… Conductivity, although, says it is in the poor range and is harder to support life…Our* *fourth test agrees with my original claim. This test Dissolve Oxygen showed a great result."* (2c)

In both Explanations #3 and #4 Paul presented separate claims without working towards developing an overall claim. In his claims he added on each new test rather than integrating them into his claim.

Mike is another student who started out really well with complete, synthesized claims for the first three explanations. He completely fell apart, however, on his fourth explanation. For his initial explanation, Mike first reported pH and temperature data separately, stating that the results of each fell in the good range for water quality standards. He then made the claim below:

> <u>Explanation #1</u>: *"The fact that both of these are good, and that there is plenty of plant life supports my idea that section 1 is healthy and can support aquatic organisms*.

Explanations #2 and #3 are also synthesized, complete claims:

> <u>Explanation #2</u>: *"I think the stream is healthy with test results in the good range. Good is able to support organisms so there will be life in the stream."* (5)

> <u>Explanation #3</u>*: I used to think the stream is healthy with test results in the good range, but after we tested for conductivity, which was poor, I think our stream is not healthy, probably in the good or fair range. Fair is not able to support organisms so there probably won't be life in the stream."* (5)

In Explanation #4, Mike's claim consists of two contradictory statements.

> <u>Explanation #4</u>: "*I think our stream is reasonably healthy, probably in the good range. Fair is not able to support organisms so there probably won't be life in the stream."* (2d)

Paul and Mike, as stated earlier, are two of five students whose initial claims were complete, even before the explanation framework was introduced. Of all five students, four also had complete claims for Explanation #2 with the other student writing a partial, but appropriate claim. For Explanation #3, only two students wrote complete claims. Of these two students, only one developed a complete claim for Explanation #4. In all, only one student wrote complete claims throughout the entire evolving explanation[10].

In total, 13 students developed complete, synthesized claims for Explanations #2, #3, and #4, even though their claims prior to the explanation framework spanned the entire gamut of possible claims: no claims (1), attempted claims with problems (2), vague claims (3), synthesized, partial claims (4), and synthesized, complete claims (5). Their pattern, overall, was *Direct*. As well, 13 other students developed complete, synthesized claims for the final explanation; their patterns were varied (*Wandering, Sawtooth, Lost then Found*) throughout the evolving explanation, but in the end they were successful. Two additional students had claims that were *Lost* for the first three iterations but who finally developed synthesized claims that were partially complete (*Lost then Found*). Combining all of the students, regardless of what path they took, 26 students developed complete, synthesized claims. Two more students developed appropriate, synthesized claims but they were incomplete. Therefore, 28 students, or just fewer than 50%, were successful at developing appropriate claims that were supported by all of the evidence.

4.6.3 Findings for Research Question Three: What are the challenges that students face in developing one claim over time?

Thirty students, or just over 50%, were unsuccessful in making an appropriate claim in the final iteration of the evolving explanation. It should be noted that 24 of these 30 students made accurate claims with two pieces of evidence in Explanation #2. These two pieces of evidence, pH and temperature, were consistent; that is, they both reflected excellent and/or good water quality.

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[10] Another student was absent for the initial claim but wrote synthesized, complete claims for Explanations #2, #3, and #4.

Table 4.2, presented earlier in the chapter, represents five categories that were developed from the data to identify types of claims students made throughout the four iterations of the evolving explanation. These include 1) No claim, 2) Attempted claim, 3) Vague claim, 4) Partial claim, and 5) Complete claim. Students' principle initial challenge to making complete claims was their lack of knowledge of scientific explanations. Once introduced to explanations, however, all but two students included a claim in their explanation. Furthermore, 80% of students were successful in making appropriate claims.

It was not until the third piece of evidence was included that more challenges for students emerged. Unlike the first two water quality tests that showed excellent and/or good results according to water quality standards (Stapp & Mitchell 1995), the third water quality test, conductivity, indicated poor water quality with too many dissolved solids. Adjusting one's claim after obtaining this new evidence that was inconsistent with a student's present claim presented a challenge for many students. This occurred when a complex phenomenon was under investigation and a previous claim was fully supported by the available evidence and then was no longer supported by new available evidence. Category 2, *Attempted claim* in Table 4.2, where students' claims showed some type of problem, was further articulated because students exhibited a wide range of challenges. Five challenges were identified and are displayed earlier in Table 4.3 and discussed here.

Challenge One: Ignored data, but described context. These students set a context for all of the water quality tests, including new tests in Explanations #3 and #4, but ignored the new evidence in their claims. They did not adjust their claims but simply kept their claims from the previous explanation even though the new evidence rendered their claim inaccurate; with this new evidence, their claim was no longer supported by the evidence. These students, however, presented evidence and reasoning later in their explanations based on the new evidence.

Challenge Two: Ignored data and included no context. Some students exhibit an inability to attend to new information; these students did not include the new water quality test in their context. They ignored new evidence in their claim and did not adjust their previous claims, even though the claim was no longer supported by all of the evidence. These students, just as those with challenge number one, presented evidence and reasoning later in their explanations based on the new evidence.

Challenge Three: Separate Claims. As new evidence emerged, these students made separate claims. They compartmentalize their claims. They are unable to synthesize the old and new evidence into one claim. These students appeared to think separately about each water quality test and generated multiple sub-claims. Sometimes these sub-claims were physically separated from one another in the explanation. It appears that these students can only focus on one piece of evidence at a time.

Challenge Four: Ignored and Separate Claims. These students ignored new evidence and therefore did not adjust their claims based on this new evidence. They also made separate claims for the various water quality tests. Just as those students with the previous challenge, these students compartmentalized their claims with little or no synthesis.

Challenge Five: "Messy." These students attempted to synthesize new evidence, some of which was inconsistent, to develop an appropriate, overall claim, but their claim was confused and messy. Students attempted, but struggled, to adjust their claim. For some students they presented no overall claim. Synthesizing several pieces of evidence into one claim was very challenging for these students. They appeared to wrestle with incorporating new ideas. In the same iteration, students moved back and forth between claims, sometimes making contradictions, often times showing signs of confusion.

4.7 Discussion

The research reported in this portion of the study builds on the work of Krajcik and McNeill and others. Often the "claim" portion of the *claim, evidence, and reasoning* framework is viewed as the easiest part for students to include (Berland, & Reiser, 2009; McNeill & Krajcik, 2011; McNeill & Krajcik, 2007; McNeill et al., 2006). Many students in this study, however, found the "*claim*" portion of this more complex explanation to be very challenging. Unlike studies related to socioscientific issues where students are often presented with conflicting reports about a phenomenon, like the study by Salder and colleagues (2004), the students in this study collected their own data, some of which was positive for freshwater organisms, and some of which was problematic for freshwater organisms. In working to explain this complex phenomenon (Was the stream healthy for freshwater organisms and how people's actions could impact the stream?) students needed to negotiate all of their evidence to support one claim.

4.7.1 Discussion for Research Question One: How do students adjust their claim as new evidence emerges?

The results indicate that when evidence is consistent (two pieces of water quality data that are both positive) and once the explanation framework is introduced that, in fact, a claim is relatively easy for students, with 80% of students making appropriate claims. These results are consistent with the situations typically described in the science education literature (Berland, & Reiser, 2009; McNeill & Krajcik, 2011; McNeill & Krajcik 2007; McNeill et al 2006). The research findings of this study, however, show that when conflicting evidence is obtained and incorporated into the explanation, the percent of students making appropriate claims decreased from 80% to 40%. Students needed to examine if their claim accounted for all available evidence (Duschl, 2007; Sampson & Clark, 2006), revise and/or reinterpret their findings based on the new evidence (Nature of Science Matrix, NGSS Appendix G, 2013) each time new data was obtained and analyzed.

I found that once a third piece of evidence was introduced, which was inconsistent with the initial claim, many students did not adjust their claims, even with various teacher supports. These results suggest that when evidence is gathered over a period of time while investigating more complex phenomenon where evidence conflicts, revising one's thinking and generating an appropriate claim based on all the evidence, is challenging. This point is further explored in the discussion section for Research Question Three that focuses on challenges.

4.7.2 Discussion for Research Question Two: What are the patterns that students' claims progress through in the various iterations of an evolving explanation?

Some students were successful to incorporate the new evidence to develop an appropriate claim and some were not. About half of the students' pathways were direct where they were able to use class discussion and teacher prepared guide sheets that included prompts for students to review their claims. As Quintana and colleagues (2004) suggest, these scaffolds supported these students in areas for sense making, process management, and articulation and reflection (2004). Palinscar (1998) stated that scaffolds can be embedded activities in a curriculum. Working with partners to complete guide sheets are one such activity. They were able use the scaffolds to assist them to organize their knowledge (Fortus & Krajcik, 2011; Roseman, Linn, & Koppal, 2008; Hmelo-Silver, & Pfeffer, 2004; NRC, 2000) to explain a complex phenomenon, the water quality of a stream for freshwater organisms, and to make appropriate claims, even with inconsistent evidence that was collected over a period of time that necessitated a revision of the original claim. The other half of students who were successful benefited from additional teacher support in the form of written feedback related to what Pellegrino and colleagues (2001) call the qualities of their work and what they could do to improve, in this case prompts about a need to revisit and reflect on their claims. The number of students who were successful at making complete, appropriate, synthesized claims increased from the 3rd to the 4th and final iteration of the explanation that included four pieces of evidence and after the teacher provided students with continued supports.

In this research, I identified eight different patterns of claims that emerged from the data (Figure 4.1). Students who were successful to generate an appropriate claim in the final iteration of the explanation took one of four different pathways: *Direct, Wandering, Sawtooth*, or *Lost than Found*. These results indicate that students developing understanding ideas at different times. Some students understood the ideas of looking at all of the evidence and then adjusting claims right from the beginning while others benefited from having more time. Additional time allowed them to wrestle with the claims, better understand teacher feedback, particularly for students who didn't generate an accurate claim until the final iteration.

Understanding complex ideas takes time (Bransford, Brown, & Cocking, R. R. 2000; Krajcik & Shin, 2013). This includes rethinking claims.

The 26 students who generated complete, appropriate claims, along with the two other students who made appropriate but partial claims represent a little less than half of the students. Just less than 50% is an improvement from the 40% of students with appropriate claims for Explanation #3. Fifty percent of students, however, were unsuccessful at generating appropriate claims. These students exhibited various patterns that included being *Lost, found, than lost*; *going well then falling apart*; and *lost from beginning to end*. A discussion of the challenges these students faced is presented next.

4.7.3 Discussion for Research Question Three: What are the challenges that students face in developing one claim over time?

I know of no research that addresses this question. Therefore, discussion of Research Question Three poses more questions than answers. Several questions emerge from this study: "Why is it so difficult for students to adjust their claims in the face of new evidence? What are the challenges that students face? What are the implications for instruction?

As presented in the findings sections, I found that once a third piece of evidence was introduced, which was inconsistent with the initial claim, many students did not adjust their claims, even with various teacher supports. Some students included separate, compartmentalized claims. Other students ignored the new evidence, even those who set a context for the additional evidence. Some attempted, yet struggled to develop a claim that incorporated the new evidence. Some students' claims reflected that they were "lost" at various points: lost from the start; lost, found, then lost, or that the early claims they generated were appropriate but that their later claims were inappropriate.

While I believe further research is needed, I offer some insight into these questions based on the findings from my study. Overall, adjusting one's claim after obtaining new evidence that is inconsistent with a student's present claim seems to be a very cognitively challenging task for many students. This project-based science unit puts students in an authentic, real-world context where they collect empirical data in real time. Students are engaged in a non-routine, open-ended, long-term investigation of a complex phenomenon. Different student groups may obtain different results and have slightly different features, either at or near the stream that may either be the cause or consequence of various results. Students may interpret data in different ways that are plausible, based on science concepts. This multitude of factors adds layers of complexity that, I believe, challenge students.

There are some students who set a context for new evidence but ignore that evidence in their claims. These students also report and analyze all of the data later in the explanation. In a sequence of sentences at the beginning of the explanation these students introduce each water quality test to the reader, including the new test, then in the claim that directly follows, they present the claim from the prior iteration of the explanation; they make no adjustment to the claim. Is this due to the old adage, "My mind is already made up, don't confuse me with the facts!"? Perhaps they have developed an initial understanding of a system, their stream section, and that makes the assimilation of new information too challenging. It may be similar to what Kuhn (1996) describes as challenges for scientists in making a paradigm shift. If expert scientists are challenged to adjust their thinking, why would novice students be more successful? Brandsford and Schwartz (2001, p.21) refer to negative transfer and "letting go" when "adapting to new situations." These new situations refer to transfer and preparation for future learning that often involve "letting go" of previously held ideas and behaviors." Perhaps students just could not let go of their previous claims even in light of new, contradictory evidence. Maybe students do not even detect incongruities or anomalies (Chinn & Brewer 1993, 1998; NRC, 2007) or they simply ignore or reject new evidence (Chinn & Brewer, 1993). Before students can let go of current claims, maybe a reflective, metacognitive component needs to be added to instruction (NRC, 2007, Choi et al., 2011). Bringing student groups together to share and then defend their claims might bring to a more conscious level a need to adjust claims that may support thoughtful reflection. This process would assist students to build knowledge through more purposeful engagement and interaction (Reiser, Berland, & Kenyon, 2012) and the more public process of discussing and critiquing claims (Berland, McNeill, Pelletier, & Krajcik, in press) could assist students to reflect about their current claims, reconcile disagreements, and then build new claims together.

Another challenge students face is working to synthesize several pieces of evidence, some of which is inconsistent, into one claim. There were students in this study who clearly thought about each water quality test but who could not synthesize ideas into one overall claim or even physically put these claims into the same space in an explanation; they made multiple claims in separate sections of the explanation, that often contradict each other. It appeared that these students could only focus on one piece of evidence at a time and wrote several "sub-claims" without synthesizing parts of the system (in this case various water quality tests from a stream) into the whole system (the overall health of the stream for freshwater organisms based on all tests). They compartmentalized their claims. This is a complex idea and as research shows, learning complex ideas takes time and often occurs when students work on a meaningful task that forces them to synthesize and use ideas (Bransford, Brown, & Cocking, 2000; Krajcik & Shin, 2013). Sophisticated understanding does not develop in a short period of time, but instead, slowly develops over time as an individual grapples to make meaning. The findings indicate, however, that with teacher support, most of these students made the transition to synthesizing these separate claims into one appropriate claim. Perhaps students have not engaged often enough in these types of experiences.

4.8 Reflections and Implications for Research and Instruction

In this section I present personal reflections based on the study including implications for future research and for instruction.

4.8.1 Experience: Rethinking and Reflection?

Is rethinking and adjusting claims in light of new evidence a task that is too cognitively challenging for many students? Or could it be those students' science experiences, or their educational experiences in general, have taught them they should complete one task and then move on to the next task? Even in classes where revision is often a component of the work, as in English classes, students begin with a rough draft and then improve and expand on the original ideas. In an evolving explanation students are improving on their original work (teacher feedback also included feedback about their evidence and reasoning) but they are also incorporating new evidence that may drastically impact their overall explanation, including a need to adjust their claim. Could it be that these 7th grade students do not have a view of science as an evidence-based field where ideas evolve over time - weeks, years, even decades and centuries - as new evidence emerges?

Based on my research, I cannot definitively say why students appear to be aware of and somewhat thinking of new evidence, as noted in the context they introduce in their explanation, but yet do not incorporate it into their new claim. I recognize, however, that this describes many students. I conjecture that, in most students' science experiences, they are not involved in activities where they gather evidence and make a claim, that could be accurate based on that evidence, then obtain new data that could serve as contradictory evidence that could render the original claim inaccurate. Students do not have these types of experiences in adjusting their thinking that would be reflected in adjusted claims. This may be the first time experiencing such a situation. Even in classrooms where students engage in writing explanations, those explanations are relatively short, a few paragraphs at most (Cavegnette, 2010); this explanation, in its final form, is much more lengthy.

For students who ignored new evidence and set no context for the new test at all, even though they reported and analyzed evidence later in the explanation, an inability to attend at all to this new information in their claims may also be similar to the previous group. Students may have made a determination that they then are unable to renegotiate as new evidence emerged; they may lack any experiences of this type of "revision" and have nothing on which to build. The result may prove too demanding for these students.

Being open to revising one's thinking based on incorporating new evidence that results in adjusting one's claims about a phenomenon and then actually developing appropriate claims may be a learned skill. Evidence from my research indicates that for some students who appear to be working at incorporating new evidence into their claims that it can be "messy". These students appear to wrestle with incorporating new ideas and need continual "nudging" (NRC 2007, p. 287) that encourage and support them to reflect. This is seen in the form of students going back and forth between claims, sometimes making contradictions, often times exhibiting confusion, but clearly, I believe, struggling to synthesize new evidence into an appropriate, overall claim. This is another area for research.

4.8.2 Electronics and Challenges to Adjusting Claims?

I have one final question related to why students might include some text related to additional evidence without incorporating it into a revised claim. I wonder if electronics inhibit or discourage students from cognitively engaging in the process. It may be that these digital natives do not reflect deeply on their thinking because digital tools enable them to easily copy, paste, add and delete text, and move text around. Could it be that students simply added the word "conductivity" to the original claim even though it resulted in a contradictory claim? Could they have followed directions to include a context for a third, and then later a fourth water quality test; they attended to these directions but either simply forgot to adjust their claim or did not attend to the more cognitively challenging task of rethinking their initial ideas? These are questions that arise from this research that I cannot answer; further research is needed. Perhaps this new research could include student interviews.

4.8.3 Additional Implications for Research

When I look solely at students whose final iteration of the evolving explanation exhibited appropriate claims, two patterns emerge. Half of these students exhibited a direct route once they were introduced to the explanation framework; with each new piece of evidence, along with classroom discussion and teacher guide sheets, they were able to revise their thinking and incorporate the new evidence into an appropriate claim. The other half exhibited some kind of problem along the way. They needed additional teacher support, but were able, in the end, to incorporate all available evidence to support their claim. These two groups together comprised a little less than 50% of the students. Why were these students successful? Further research to determine why these students were successful is needed. The other half of the students' challenges prevented them from developing appropriate claims. This research sheds some light into the challenges that students face. To further understand these challenges additional research is needed.

4.8.4 Implications for Instruction

Results from this study present many implications for instruction. First, developing curriculum where students engage in authentic, open-ended investigations that more closely mirrors what scientists do is critical (NRC, 2011). Specifically, students need opportunities that involve them in a process of revising claims as new evidence comes to light (NGSS 2013, Appendix H). This is not what many students presently experience. Understanding develops over time. Just as with any new undertaking students need multiple experiences that allow them to develop an understanding of the practice (Fortus & Krajcik 2011; NRC 2000, 2010, 2013; Nelson & Hammerman, 1996). Students also need support in this challenging endeavor. Developing a set of teacher strategies and scaffolds to assist students throughout this process will be valuable for teachers and curriculum designers. The teacher in this study provided several scaffolds and viewed herself as a coach (NRC, 2000, p. 177). A close look at the completed student guide sheets will shed more light on whether students utilized them in appropriate ways and then whether or not students used the guide sheets when writing their explanations. Teachers may need to be very explicit when introducing the idea of an evolving explanation. Additional discussions and scaffolded guide sheets also serve to support students. Reiser, Berland, and Kenyon (2012) suggest providing students with time to argue "for their explanations can strengthen those explanations and help construct a consensus explanation" (p. 13). A similar strategy could be used for building claims during various iterations of an evolving explanation; as students share and critique each other's claims the process may allow students to more deeply reflect on their own claims and make adjustments, as needed. This more public sharing of claims, along with teacher feedback throughout the process may serve to move students through the process at greater levels of sophistication. Developing curriculum with evolving explanations provides students with a more authentic scientific experience that aligns with the Framework for K – 12 Science Education.

4.9 Summary

Students' science experiences need to provide them with "engaging opportunities to experience how science is actually done" (NRC, 2012, p. 1) while assisting them to develop organized knowledge structures to explain phenomena and solve problems (Fortus and Krajcik, 2011; Roseman, Linn, & Koppal, 2008; Hmelo-Silver, Pfeffer, 2004; NRC 2000). Constructing evidence-based explanations is stressed throughout the *Practice Matrix* and in the *Nature of Science Matrix* within The New Framework for K-12 Science Education document (NRC 2012) and the NGSS (2013). Scientists construct explanations to explain the natural world. The actual work of scientists involves a continual process of revising claims as new evidence comes to light. This is part of the nature of science (NGSS 2013, Appendix H). Students need similar opportunities. This part of the thesis has attempted to shed light on how students make claims and examine the challenges that students face in adjusting their claims when incorporating new evidence into one scientific explanation, deemed an "evolving explanation" that develops over time.

CHAPTER 5

Supporting the Development of Science Understanding using an Evolving Explanation with Synergistic Scaffolds

5.1 Overview of the Chapter

In this chapter, I examine the development of students' science ideas across the four iterations of the evolving explanation to explore how students move towards developing more sophisticated understanding of those science ideas that may then be used as part of reasoning in the scientific explanation; in order to reason, one must have an understanding of science ideas. Research reported here, therefore, will look solely at students' science ideas across four iterations and will respond to Research Questions Four and Five.

5.2 Problem Statement

Research evidence shows that reasoning is the most difficult part of an explanation (Berland & Reiser, 2009; Gotwals & Songer, 2006; NRC 2007; McNeill & Krajcik, 2006). In order to reason, students must have an understanding of science ideas; they should use this understanding to select certain data and show why these data count as evidence and also support the claim. This reasoning requires discussion of science ideas. Whether the science ideas students hold are connected to other science ideas resulting in integrated understanding (Fortus and Krajcik, 2011; Roseman et al., 2008; Hmelo-Silver, Pfeffer, 2004; NRC 200008) or if the ideas are merely isolated bits of unconnected facts will be reflected in how sophisticated students' explanations of phenomena will be. If ideas are well organized, like experts, students should be able to apply their understandings (Bransford, Brown & Cocking, 2000; Chi, Feltovich, & Glaser, 1981; Hmelo-Silver and Pfeffer 2004). If, on the other hands, those ideas are disconnected, students will be challenged to use their understanding to explain phenomena. Three-dimensional learning environments, like the classrooms in this study, that foster understanding scientific core ideas and crosscutting concepts through engagement in scientific practices, like constructing explanations, help students to understand the broader and deeper levels of scientific knowledge and how to make use of that knowledge (NRC, 2012; Krajcik & Shin, 2013). The curriculum in this study worked to build and connect ideas across the curriculum where students were engaged in an authentic, non-routine, long-term investigation.

Writing scientific explanations, particularly incorporating science ideas as part of reasoning, is a complex undertaking that requires time and feedback. Learning any complex ideas takes time and often occurs when students work on a meaningful task that forces them to synthesize and use ideas (Krajcik & Shin, 2013, Bransford, Brown, & Cocking, 2000). One such meaningful task is working to understand and then explain phenomena. The goal of constructing one explanation over a period of time is to support students towards developing integrated understanding utilizing the explanation framework as the vehicle by which students are supported to develop a rich, sophisticated "story" of explaining water quality by using the results of various water quality tests. The aim is to assist students to learn how to develop (construct) the richest, evidence-based science "story" to explain various phenomena, in this case related to water quality of a stream.

Developing curriculum with an iterative rather than sequential focus over time is paramount (Bransford, Brown & Cocking, 2000; Fortus & Krajcik J, 2011; NRC, 2013; NRC 2010; Nelson & Hammerman, 1996). The iterative approach of constructing an evolving explanation that includes practice and feedback (Black, 2003; Bransford, et al., 2000; Krajcik & Czerniak, 2014; Pellegrino et al., 2001) has the potential to provide students with an experience that allows them to rethink and revise their ideas as well as more thoughtfully analyze and incorporate new science concepts when writing about new evidence. In other words, as students collect new data about the phenomenon under study, qualitative and quantitative water quality test measures over a six-week period in and near a stream in this particular study, they need to understand different science ideas in order to make sense of that data. Writing earlier versions of the explanation may provide students with experiences and the building of knowledge structures that prepare them to more fully utilize science ideas when incorporating new evidence and new science ideas into an existing explanation. Bransford's and Schwartz's (2001) emphasize thinking about transfer as "preparation for future learning" (PFL) with a focus on "extended learning" rather than one-time performance tasks. When students are well prepared for future learning, they state, they are more able to transfer that learning to a new situation. This new situation can be exploring a new aspect of more complex phenomena that is part of a larger system and that entails new science ideas and perhaps the use of new tools for further exploration. In the case of the stream, the new aspects are additional water quality measures. Understanding these measures and their relationship to the health of the stream necessitates that students understand new science ideas and that they incorporate this understanding into their scientific explanation. As students develop their explanation over time, not only do they have the potential to include more science ideas, but those science ideas can become more connected allowing students to tell a richer, more sophisticated "story" about the phenomenon, in this case, the health of a stream for organisms based on several different pieces of evidence. This places them on a trajectory to move from novices towards having more expertise (Brandsford & Schwartz, 2001). With multiple opportunities and with different contexts, students are assisted to move away from understanding science ideas as bits of disconnected facts and to begin to organize their knowledge around core science ideas in much the same way that experts do (Chi, 2011; Hmelo-Silver & Pfeffer, 2004; Rottman et al., 2012). The entire process should also assist students to better understand the nature of science (NGSS 2013, Appendix H).

5.3 Research Questions: Integrated Understanding – Science Ideas

The research questions examined in this chapter include:

4. As students engage in writing an evolving explanation, how does their understanding of science ideas develop over time?
5. How does the practice of analyzing data/evidence and writing the first two iterations of an evolving explanation allow students to transfer their learning to new situations?

5.4 Data Sources and Data Collection

Each of four iterations of the evolving explanation for all students was collected. Teacher feedback from Explanations #2 and #3 was also collected. Lastly, student scores on an end of the semester examination related to science concepts of the four water quality measures (pH, temperature, conductivity, and dissolved oxygen) were collected.

Students' initial explanation (Ex1) took place after two separate data collection episodes where students collected pH and then temperature data. This explanation was written before students were introduced to the Explanation Framework. Water quality data from all groups was shared during a class discussion after each data collection episode with particular focus on identifying similarities and differences in the results. Using these two water quality measures students were simply asked to individually *"Write what you think a scientist would write about the health of the stream for freshwater organisms"* based on what was known. The Explanation Framework, which served as a scaffold, was then introduced to students (McNeill & Krajcik, 2011) and, together with water quality partners, students completed a teacher prepared scaffolded guide sheet (Windschitl et al., 2011; McNeill, et al., 2006; Palinscar, 1998; Quintana et al, 2004; Tabak, 2004) with the purpose of supporting students in constructing the explanation. It included prompts to assist students to consider various science ideas, including the purpose of conducting the test, and both causes for their results and effects (consequences) those results might have on organisms in the stream. It also provided students with a structure for writing the various components of an explanation. The teacher also moved from group to group to assist students. Figure 5.1 shows a portion of the guide sheet that consists of prompts for science ideas including two spaces, one for students to record notes for pH and the other for temperature. The entire guide sheet may be found in Appendix C.

REASONING: explain and discuss results: Use scientific concepts from background information with your evidence (Test results and physical data) **What** do the results Mean? Standard. Are these results positive Or negative? Why? consequences from background (examples) **Why** did you get these results? Incorporate the causes completely discuss/explain- Use info. from p.19 & p.8 (hand-outs)		

Figure 5.1: Portion of an Explanation Guide Sheet for Student Notes: Science Ideas

Students were then instructed to use their guide sheet, which served as an outline, and individually revise their initial explanation (Ex1) with the expectation to include discussion of science ideas as part of their reasoning. This second iteration became Explanation #2 (Ex2). The teacher then provided students with electronic feedback that included, among other things, comments related to science ideas. Much has been written about the use of feedback and student learning (Black, 2003; Bransford, et al, 2000; Krajcik & Czerniak, 2014; Pellegrino et al., 2001). Following various lessons related to dissolved solids, student groups next collected a third piece of data, conductivity. Data from each group was shared and discussed with the entire class. Student groups completed another, less scaffolded guide sheet to support them in continuing to develop their explanation, now based on three pieces of evidence. Students used these notes to expand their Explanation #2. Additionally, students were to incorporate teacher feedback from Explanation #2, into this third Explanation (Ex3). This was followed by another iteration of teacher feedback, now related to pH, temperature, and conductivity tests. A fourth piece of data, dissolved oxygen, was collected following various lessons and the same cycle occurred; students shared data in class, student groups discussed and analyzed data taking notes, and students individually incorporated the new data into their existing explanation. This final iteration of the explanation was Explanation #4 (Ex4). Each time students were expected to include discussion of appropriate science ideas, which often related to causes and effects, as part of their reasoning. Students were also expected to incorporate teacher feedback.

At the completion of the entire water unit, students took a comprehensive examination that was prepared by the teacher that included water quality concepts from each of the four water quality measures. These questions mainly included multiple-choice items and short answer questions that required two to four sentences to complete. These exams were collected.

5.5 Data Analysis - Overview

A comprehensive concept map (Appendices E-H) (Novak & Gowin, 1984) created by the researcher represented all of the science ideas and the relationships and connections between them. Three water ecology experts evaluated this concept map for scientific accuracy verifying that it contained all of the science ideas and all of the relationships. Next, the concept map was used to create a detailed rubric, using a base rubric for analyzing scientific explanations (McNeill & Krajcik, 2011). In order to do this, concepts and their connections were translated into statements, one by one, and became part of the rubric. The water ecology experts also verified the rubric for scientific accuracy. The rubric then, reflected accurate science ideas and meaningful connections and could be used to infer student understanding of the science ideas for the various water quality measures. Higher scores on the rubric were evidence of more sophisticated understanding of science concepts.

In addition to the science concepts and their relationships, the reasoning portion of the rubric included a section to record whether or not students connected their science understanding to their evidence, thus reasoning. Reasoning requires discussion of appropriate scientific ideas, and development of scientific ideas is the focus of this chapter; therefore, the connections of the reasoning to evidence part of the rubric are not included. Exploring connections students make between science ideas and evidence is the focus of Chapter 6.

Figure 5.2 (also Appendix E) illustrates the pH portion of the concept map. Figure 5.3 is the translation of those concepts into statements that became the pH portion of the rubric. Students' earned one point for each accurate idea. Ideas that were inaccurate or missing were scored as zero. As seen in the pH portion of the rubric (Figure 5.3) the maximum number of possible points was six.

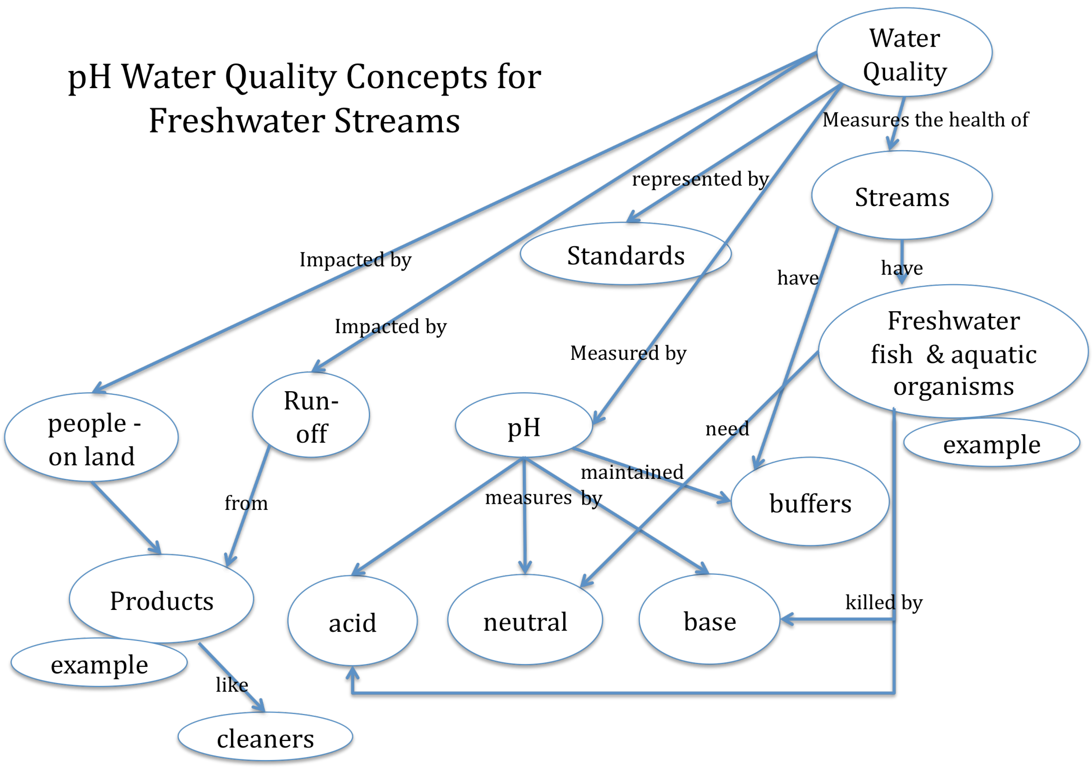

Figure 5.2: pH portion of Water Quality Concept Map

Reasoning – **Science Concepts Portion**
__0__ Does not provide reasoning or provides inappropriate reasoning.
Provides all reasoning components: WHAT evidence means and WHY these results? pH Reasoning: **Science Ideas Portion** __1__ Stream is acidic? Basic? Neutral? correct __1__ Correct Standard –most neutral a couple slightly basic (excellent or good – a couple fair) positive results: __1__ Most organisms need neutral pH or will die __1__ Example: name of organisms and pH range needed __1__ Example - product and pH from land-use and run-off __1__ Buffers – define

Figure 5.3: Translation of pH concepts into statements that became the pH portion of the rubric.

This same process was used for developing rubrics for temperature, conductivity, and dissolved water quality measures as well. It should be noted that, in addition to reasoning, the complete rubric included claim, evidence, rebuttal, and action steps in order to gain much more comprehensive insight into how students' explanations evolved over time. The research reported here, however, focuses solely on students' development of science ideas over the course constructing an explanation over four iterations. For all iterations of the explanation, the science ideas from students' reasoning scores were compiled for each water quality measure that was included.

5.5.1 Data Analysis Research Question Four: As Students engage in writing an evolving explanation, how does their understanding of science ideas develop over time?

To answer research question four, which explores if students developed a more sophisticated understanding of scientific ideas over time as they gained more experience in the practice of writing explanations, student scores from the rubric were used to conduct statistical analyses that included one-way repeated measures ANOVA for each separate water quality measure. Repeated measures were obtained for four iterations of pH and four iterations of temperature. In addition, repeated measures were obtained for two iterations of conductivity data. Dissolved oxygen data was not included, as it was part of the final water quality measure and did not undergo revision.

To illustrate the procedure of obtaining rubric scores, I present an example of one student's development of pH ideas through the four iterations of his explanation. Included is Paul's writing, how his writing would map onto the pH concept map, his rubric scores, and some teacher feedback that was provided in which he needed to incorporate. Portions of the writing that are accurate concepts in the rubric are underlined. Vague or inaccurate concepts were scored as zeros.

Paul's pH portion from his Initial Explanation, Ex1:

Paul's Initial Explanation (Ex1) that responded to the question, *What do "you think a scientist would write about the health of the stream for freshwater organisms" based on what we know now?* included the following discussion about pH:

> *<u>"pH is the testing of if our stream is acidic, basic, or neutral.</u> This is done on a scale that goes from 0-14. Our stream is mainly from 6-8 on the scale. <u>This means the water is in the neutral zone. Neutral is the area that can support every organism.</u> This tells us that not many acidic or basic pollutants have entered our stream. <u>If the stream is acidic or basic the water cannot support life and things begin to die."</u>*

Science ideas that Paul incorporated into his Initial Explanation (Ex1) were mapped onto the pH portion of the concept map in Figure 5.4 (highlighted). Based on the rubric, Paul earned two out of the possible six points.

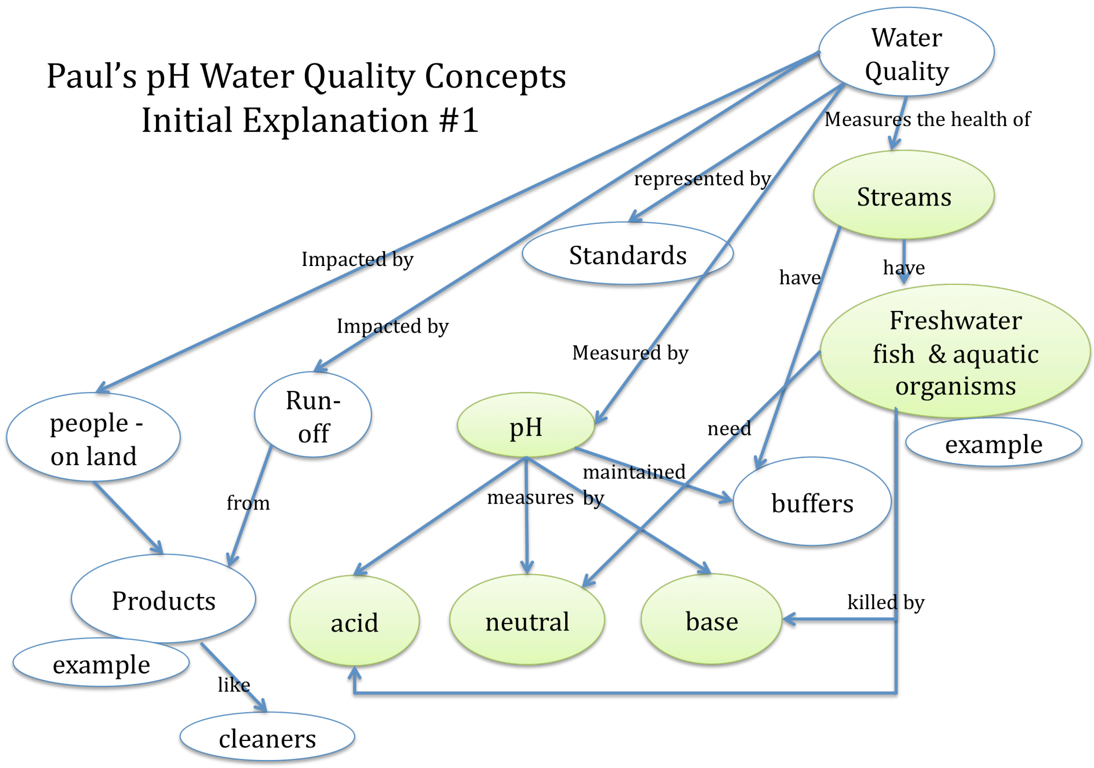

Figure 5.4: Paul's Initial Explanation: Rubric Score - 2/6 points

Paul's pH portion from Explanation #2

Following the introduction of the Explanation Framework, Paul revised his initial explanation and his pH portion looked like this:

> *"pH is the testing of if a substance is acidic, basic, or neutral. It goes on a scale that goes from 0-14. 6-8 is in the neutral zone. We choose three locations; A, B, and C. Location A had a neutral pH of 7.5. Location B had the same pH. Location C had a little more acidic. It had a still neutral zone pH of 6.5. All of our locations are in the excellent range of Water Quality Standards (6.5-7.5). As my graph says these are not harmful results. These results mean that all organisms are able to inhabit this area. They are positive and environmentally friendly results. If pH gets too acidic or basic it has the power to kill off the organisms. Fortunately we have a good result. There are no factories in the area dumping chemicals into the stream. We are also very protective of our storm drains at Greenhills. Earlier 7th graders*

have put badges on them to emphasize the harm of dumping into the storm drains."

Again, accurate concepts in the rubric are underlined. Figure 5.5 represents ideas that Paul incorporated into his revised explanation (Ex2) mapped onto the pH portion of the concept map that are added to Paul's initial map. Based on the rubric Paul now earned three out of the possible six points.

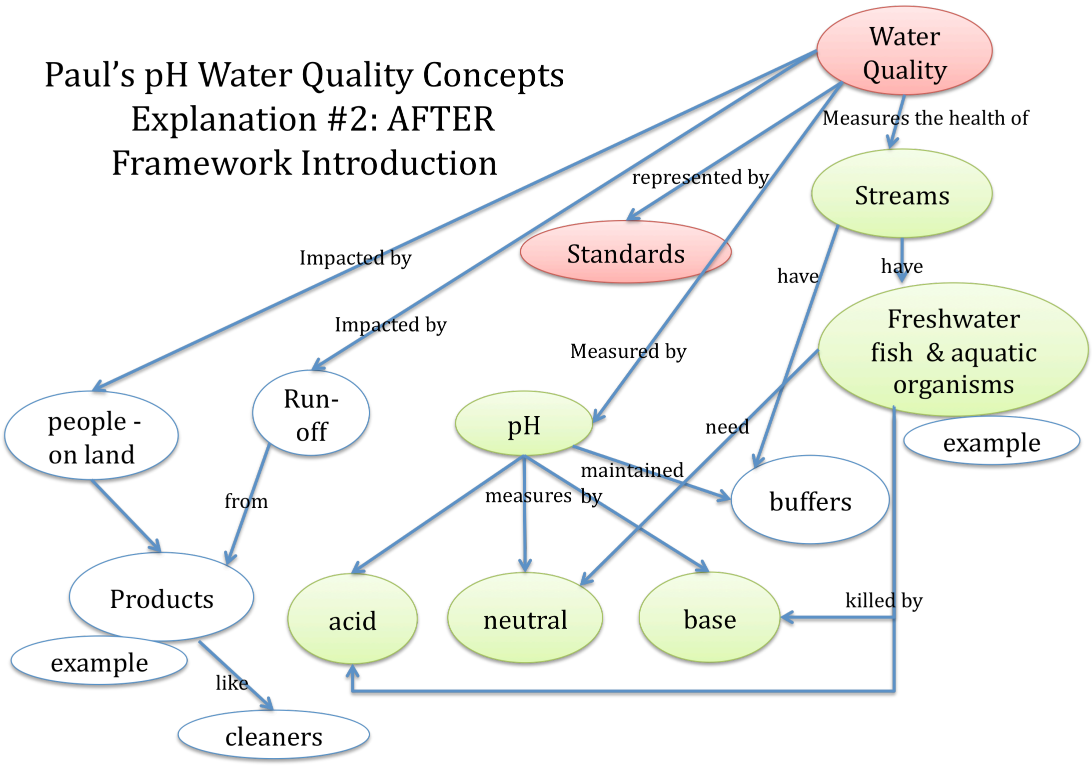

Figure 5.5: Paul's Explanation #2 (Ex2): Rubric Score - 3/6 points

The teacher provided feedback to Ex2. Here is some teacher feedback that Paul received from Ex2. In response to Paul's statement that "*all organisms are able to inhabit this area.":*

> Teacher comment: "*Can you provide 2 specific examples from p.19 and the pH range they need to live?"*

In response to Paul's comment that 7th graders have put badges (permanent stickers that inform people, "Do not dump. Leads to rivers.") on storm drains:

Teacher comment: *"Great – can you talk about what substances and from where could impact the stream's pH – car products we tested etc. you reference dumping INTO storm drains – but people products can get into storm drains without direct dumping -discuss."*

In response to Paul's statement that there were "*no factories in the area dumping chemicals into the stream*":

Teacher comment*:* "*Good – another reason might be buffers – define/discuss*"*.*

Paul's pH portion from his Explanation #3

Now, in Explanation #3, Paul incorporated teacher feedback as well as science ideas related to conductivity, a third water quality measure for which students obtained data. Here is Paul's pH portion of Explanation 3 (Ex3) after receiving teacher feedback with accurate concepts underlined:

"<u>pH is the testing of if a substance is acidic, basic, or neutral.</u> It goes on a scale that goes from 0-14. 6-8 is in the neutral zone. We choose three locations; A, B, and C. Location A had a neutral pH of 7.5. Location B had the same pH. Location C had a little more acidic. It had a <u>still neutral zone pH of 6.5. All of our locations are in the excellent range of Water Quality Standards</u> (6.5-7.5). As my graph says these are not harmful results. The <u>largest variety of animals can only live from 6.5-7.5. Snails, clams, and mussels live in 7-9. These results mean that all these organisms are able to inhabit this area.</u>

<u>If pH gets too acidic or basic it has the power to kill off the organisms.</u> Fortunately we have a good result. There are no factories in the area dumping chemicals into the stream. <u>Buffers also help the numbers. A buffer is a natural occurring chemical that helps maintain a neutral pH. The little pollution we get the buffer can take care of.</u> We are also very protective of our storm drains at Greenhills. <u>Storm drains are connected with non-point</u>

source pollution. Pollutants can get onto the streets, when it rains them downhill, this is called runoff. The pollutants get to the storm drains which leads the pollutants to the streams. *Earlier 7th graders have put badges on them to emphasize the harm of bad runoff into the storm drains. These chemicals include car oil and antifreeze from things like leaks from cars. There weren't very many bubbles, and they are an indicator of chemicals. From this there are little chemicals."*

Mapping these additional ideas onto the pH concept map produced a more filled in concept map (Figure 5.6). Based on the rubric Paul now earned five out of the possible six points.

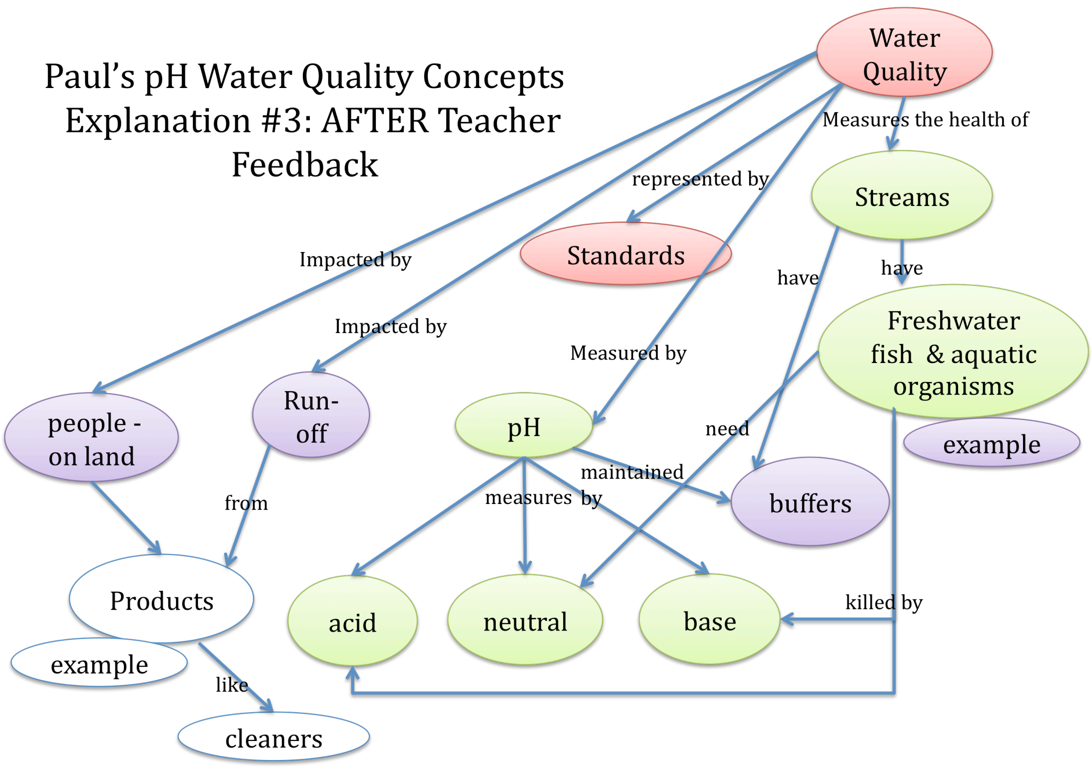

Figure 5.6: Paul's Explanation 3 (Ex3): Rubric Score - 5/6 points

After completing this explanation, Paul received the following teacher feedback:

Teacher comment: *"Car oil doesn't have a pH"* and *"....with a pH of.....?"*

in response to his statement:

"chemicals include car oil and antifreeze from things like leaks from cars."

Paul's pH portion from his Explanation #4

Paul incorporated this feedback as well as science ideas related to dissolved oxygen, into the fourth and final iteration of his evolving explanation, Explanation #4 (Ex4). Following is the pH portion of Paul's explanation with accurate concepts underlined:

> *<u>"pH or the potential of hydrogen is the testing of if a substance is acidic, basic, or neutral</u>. It goes on a scale that goes from 0-14. 6-8 is in the neutral zone. We choose three locations; A, B, and C. Location A had a neutral pH of 7.5. Location B had the same pH. Location C had a little more acidic. It had a <u>still neutral zone</u> pH of 6.5. <u>All of our locations are in the excellent range of Water Quality Standards</u> (6.5-7.5). As my graph says these are not harmful results. <u>The largest variety of animals can only live from 6.5-7.5. Snails, clams, and mussels live in 7-9. These results mean that all these organisms are able to inhabit this area. If pH gets too acidic or basic it has the power to kill off the organisms.</u> Fortunately we have a good result. There are no factories in the area dumping chemicals into the stream. <u>Buffers also help the numbers. A buffer is a natural occurring chemical that helps maintain a neutral pH. The little pollution we get the buffer can take care of. We are also very protective of our storm drains at Greenhills. Storm drains are connected with non-point source pollution. Pollutants can get onto the streets, when it rains them downhill, this is called runoff. The pollutants get to the storm drains which leads the pollutants to the streams. Earlier 7th graders have put badges on them to emphasize the harm of bad runoff into the storm drains. These chemicals include windshield wiper fluid that has a pH of 8.4. Another one is antifreeze which has a pH of 9.3. These chemicals come from things like leaks from cars</u>. There weren't very many bubbles, and they are an indicator of chemicals. From this there are little chemicals."*

Figure 5.7 illustrates the final pH concept map for Paul. Based on the rubric he now earned all possible points.

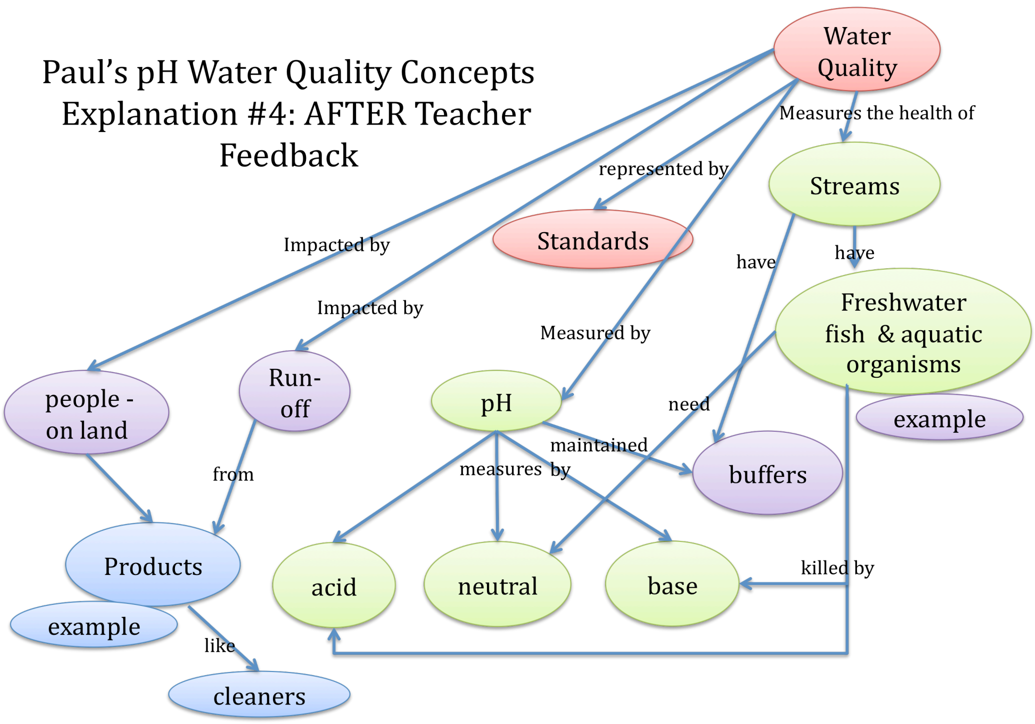

Figure 5.7: Paul's Explanation 4 (Ex4): Rubric Score - 6/6 points

5.5.2 Data Analysis Research Question Five: How does the practice of analyzing data/evidence and writing the first two iterations of an evolving explanation allow students to transfer their learning to new situations?

To answer research question five to see if with experience, students more thoughtfully analyzed and incorporated new science concepts when writing about new evidence, students' rubric scores used once again. A one-way repeated measures ANOVA was conducted to compare mean scores of students' science ideas from each water quality measure that were written by students for the first time after they were introduced to the explanation framework. Weighted means were used because there were different total possible points for each water quality measure; weighting scores ensured equal value. These were the explanations written after the Explanation Framework was introduced and included pH and temperature science ideas from Explanation #2 (Explanation 1 was written prior to knowledge of the explanation framework), conductivity from Explanation #3 (this was new evidence and was the first time students incorporated science ideas related to conductivity), and dissolved oxygen from Explanation #4 (this was now new evidence and science ideas). Conductivity concepts in Explanation #3 and dissolved oxygen concepts in Explanation #4 were viewed as transfer tasks; these were new science ideas that were incorporated into the evolving explanation for the first time. Finally, a comparison of student content scores of science ideas from the four water quality measures from a teacher prepared examination that was taken by students after the entire project was utilized to determine whether or not the different water quality measures had varying degrees of difficulty for students.

5.6 Findings

In this section, findings will be reported for both research question four, related to developing understanding over time, and research question five related to whether students were able to transfer their learning to new situations.

5.6.1 Findings for Research Question Four: As students engage in writing an evolving explanation, how does their understanding of science ideas develop over time?

Research question four explored if students developed more sophisticated understanding of science ideas as they wrote an evolving explanation. Looking at how students' science ideas developed across the various iterations of the explanation, results indicated a significant effect. Figure 5.8 illustrates student science scores on the rubric from their initial explanation (Ex1). Of a possible six points for pH, the majority of students scored zero or one. In contrast, Figure 5.9 compares science scores from Explanations #1 and #4 reflecting a major shift in student scores with most students scoring five or all six points.

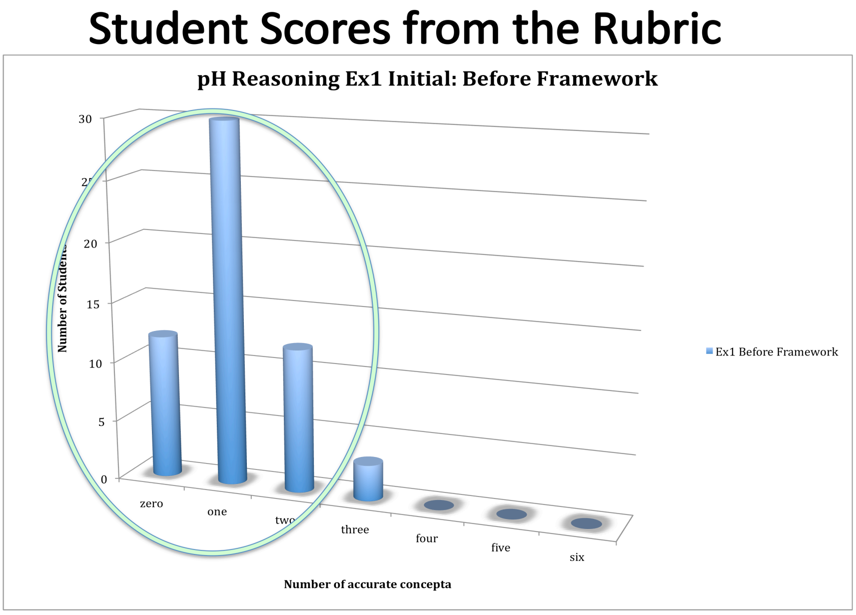

Figure 5.8: Science Scores of Initial Explanation (Ex1)

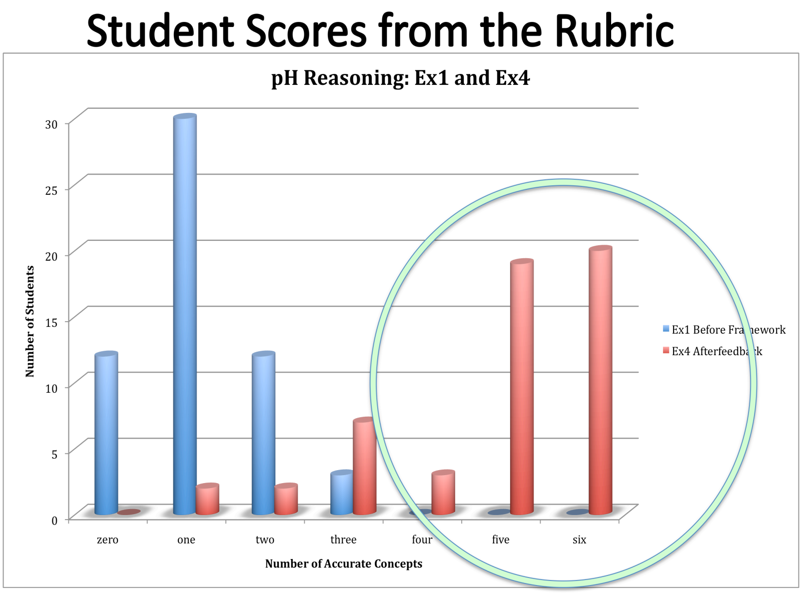

Figure 5.9: Science Scores: Initial Explanation (Ex1) compared to Final Explanation (Ex4)

The results for the one-way repeated measures ANOVA for the water quality measure of pH across the four iterations with the students who completed each explanation are presented in Table 5.1 and Figure 5.10. Results show a significant effect over the four iterations [Wilks' Lambda = 0.14, $F(5, 48) = 99.25$, $p<0.001$, multivariate partial eta squared – 0.86.]

Table 5.1: ANOVA results showing students' pH science ideas across an evolving explanation (n=51)

Explanation		M	SD	df	F	Sig.
pH	Ex1	1.18	.79	5	99.25	.000
	Ex2	2.51	1.30			
	Ex3	4.08	1.59			
	Ex4	4.78	1.40			

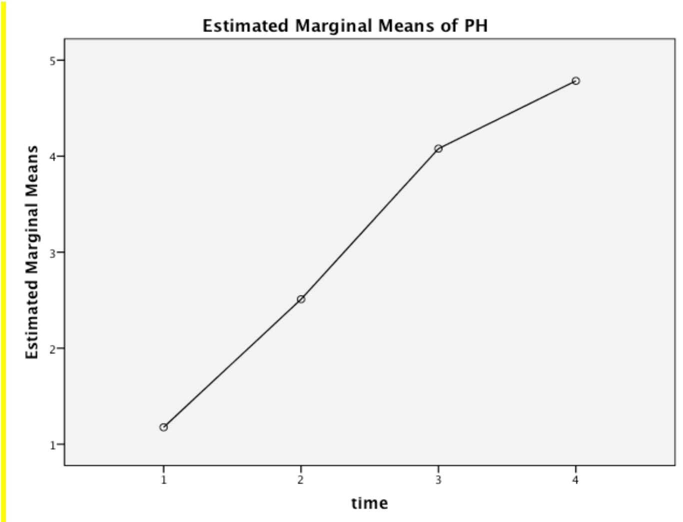

Figure 5.10: Student pH science ideas across an evolving explanation (n=51)

These results were consistent for temperature. One-way repeated measures ANOVA of the development of science ideas associated with the temperature water quality measure across the four iterations with the students who completed each explanation are presented in Table 5.2 and Figure 5.11. Results show a significant effect over the four iterations [Wilks' Lambda = 0.19, $F(5, 48) = 67.99$, $p<0.001$, multivariate partial eta squared – 0.81.]

Table 5.2: ANOVA results showing student development of temperature science ideas across an evolving explanation (n=51)

Explanation		M	SD	df	F	Sig.
Temp	Ex1	1.24	.95	5	67.99	.000
	Ex2	3.27	2.09			
	Ex3	5.20	2.71			
	Ex4	6.27	2.39			

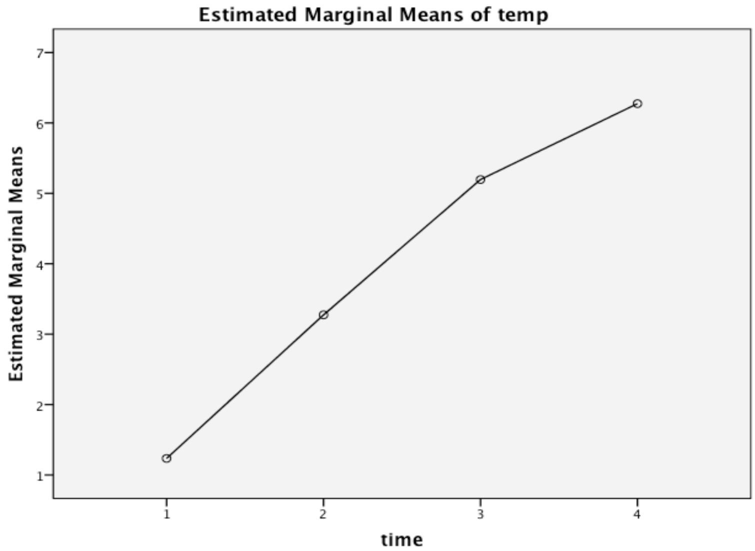

Figure 5.11: Temperature Science Scores across Four Iterations of the Explanation

Finally, one-way repeated measures ANOVA of conductivity results across iterations of Explanations #3 and #4 show a significant effect as well [Wilks' Lambda = 0.60 $F(0, 52) = 35.34$, $p<0.001$, multivariate partial eta squared – 0.41].

Table 5.3: ANOVA results showing student development of Conductivity science ideas across an evolving explanation (n=54)

Explanation		M	SD	df	F	Sig.
Conduct	Ex3	4.19	2.08	0	35.34	.000
	Ex4	5.42	1.78			

5.6.2 Findings for Research Question Five: How does the practice of analyzing data/evidence and writing the first two iterations of an evolving explanation allow students to transfer their learning to new situations?

Research question five explored if students more thoughtfully analyzed and incorporated new science concepts when writing about new evidence; this explored if students transferred their experiences to new situations. Using student scores from the first time they wrote about pH and temperature concepts (Ex2) with knowledge of the explanation framework, and comparing them with the first time they wrote about conductivity concepts (Ex3) and dissolved oxygen concepts (Ex4) would provide evidence if students transferred their learning to new situations.

Figure 5.12 illustrates the conductivity portion of the Water Quality Concept Map (Appendix G) that includes Paul's initial science ideas related to conductivity mapped onto it. Comparing Paul's pH concept map for Explanation 2 from earlier (Figure 5.5) with this map, Paul's rubric score for pH was 3/6 points and his rubric score for conductivity was 6/7 points.

A one-way repeated measures ANOVA of the weighted mean scores the first time students discussed science ideas from each water quality measure, but *after* they were knowledgeable in using the Explanation Framework was conducted. Results showed a significantly effect for time [Wilks' Lambda = 0.48 $F(5, 49) = 17.83$, $p<0.001$, multivariate partial eta squared – 0.52.] These results are illustrated in Table 5.4.

The first time students include conductivity (the 3rd water quality measure) and dissolved oxygen ideas (the 4th water quality measure) into their explanations, the number of science ideas they included were significantly higher than the numbers of science ideas included the first time students incorporated pH and temperature ideas (the first two water quality measures). All of these comparisons were made after the Explanation Framework was introduced. Figure 5.13 illustrates these differences.

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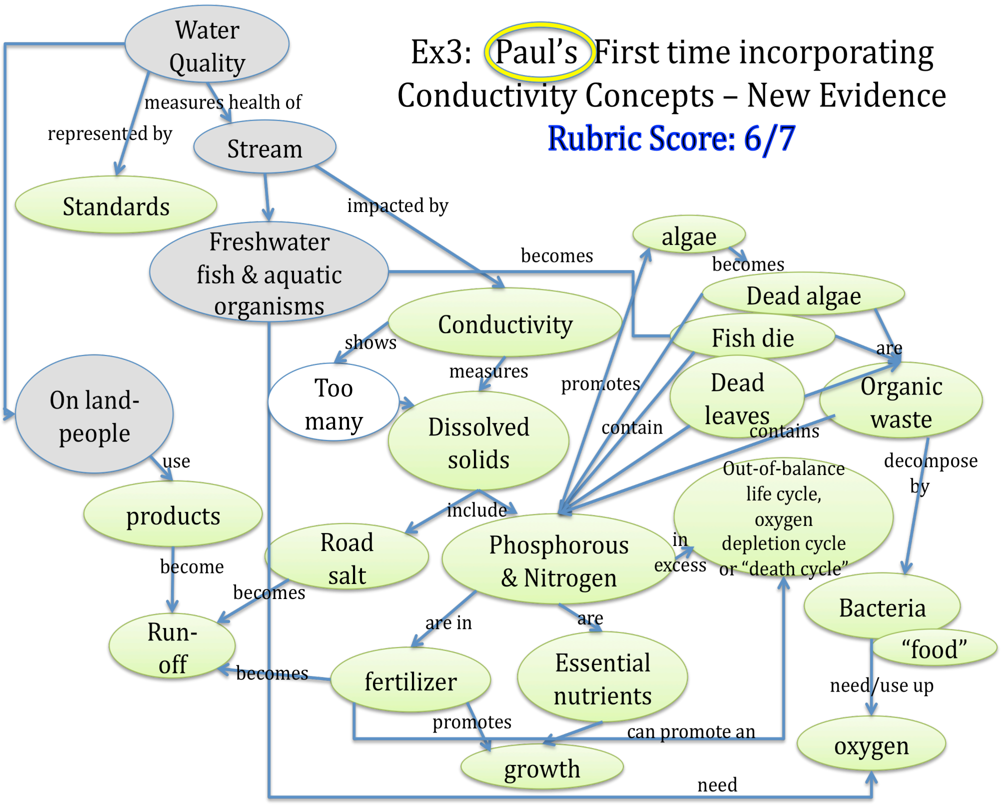


Figure 5.12: Paul's Explanation 3 (Ex3): First time incorporating Conductivity Concepts. Rubric Score 6/7 points

Table 5.4: Student Science Ideas - first time *after* introduction of *Claim, Evidence, Reasoning n=52*

Explanation		Weighted Mean	Std. E	df	F	Sig.
pH	Ex2	52.50	3.77	5	17.83	.000
Temp	Ex2	45.23	4.06			
Conduct	Ex3	75.81	5.22			
Oxygen	Ex4	76.46	3.99			

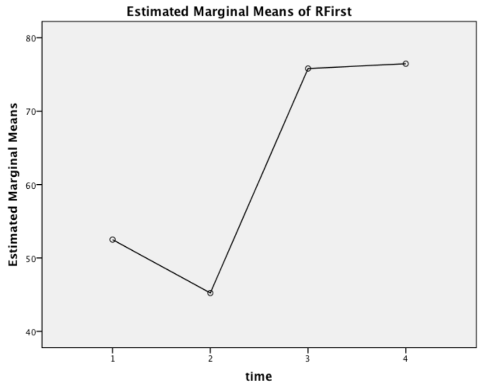


Figure 5.13: Weighted Mean: First time incorporating science ideas for each water quality measure

Were conductivity and dissolved oxygen concepts simply easier for students to grasp? To investigate this question scores students earned on an end of the semester, teacher prepared examination, were compared. Table 5.5 is a comparison of test results that includes the means and standard deviations for the results of students' scores on examination questions related to science ideas of the four water quality measures.

Table 5.5: Comparing students examination scores of science ideas (N=54)

Water Quality Measures	Mean	Std. Deviation
pH	91.4	11.01
Temperature	94.3	11.57
Conductivity	86.7	10.32
Dissolved Oxygen	92.8	10.80

The test results in Table 5.5 suggest that students had greatest difficulty with science ideas related to conductivity; these concepts may have been more challenging for students. Comparison of pH, temperature, and dissolved oxygen concepts showed no statistical difference.

5.7 Discussion

In this chapter I report on a portion of the study that examined how students developed understanding of science ideas that may be used for reasoning in a scientific explanation. Reasoning is the most challenging part of an explanation

(Berland & Reiser, 2009; Gotwals & Songer, 2006; NRC 2007; McNeill & Krajcik, 2006). If students are to reason, they must have an understanding of science ideas. The New Framework for K-12 Science Education (NRC 2012) calls for students' learning experiences to be a blend of practices, crosscutting concepts, and core ideas. In this study, students were involved in a rich context related to science ideas associated with water quality and human impact on water quality, crosscutting concepts of cause and effect, and the scientific practice of constructing one explanation, over a period of six weeks, called an evolving explanation (Novak & Treagust, 2013). Through the iterative process (Bransford et al., 2000; Fortus & Krajcik, 2011; NRC, 2013; NRC 2010; Nelson & Hammerman, 1996) of constructing their explanations, students both revisited concepts and incorporated new concepts as new evidence was obtained. The process included both teacher scaffolds (Windschitl, et al., 2011; McNeill, et al, 2006; McNeill & Krajcik, 2011; Palinscar, 1998; Quintana et al, 2004; Tabak, 2004) and teacher feedback (Black, 2003; Bransford, et al., 2000; Krajcik & Czerniak, 2014; Pellegrino et al., 2001). First, I discuss findings that look at the building of student ideas across time; in order to reason, students must have an understanding of science ideas. Second, I look to see if an iterative process assisted students to be better prepared for future learning (Bransford & Schwartz, 2001) when incorporating new evidence into an existing explanation.

5.7.1 Discussion - Research Question Four: As Students engage in writing an evolving explanation, how does their understanding of science ideas develop across time?

Findings show that students included few, if any, science ideas when initially writing about phenomena, consistent with research that finds reasoning to be the most challenging aspect of developing explanations (Berland & Reiser, 2009; Gotwals & Songer, 2006; NRC 2007; McNeill & Krajcik, 2006). Students need understanding of science ideas in order to reason. I found that utilizing an iterative approach where students develop one explanation over time (Novak & Treagust, 2013), assisted students to develop understanding of science ideas that can then be used to reason in an explanation. One-way repeated measures ANOVA for the water quality measures of pH and temperature across the four iterations and for the two iterations of conductivity water quality tests, showed significant effects. These results are presented in Tables, 5.1, 5.2, and 5.3.

Just like McNeill & Krajcik, (2009) and Tabak (2004), I found that synergistic scaffolds worked together to support students to build understanding. After learning about the Explanation Framework (McNeill & Krajcik, 2011) and with synergistic scaffolds in the form of classroom discussions, working with partners using scaffolded guide sheets (Windschitl et al., 2011; McNeill, et al, 2006; McNeill & Krajcik, 2011; Palinscar, 1998; Quintana et al, 2004) and feedback from the teacher (Black, 2003; Bransford, et al, 2000; Krajcik & Czerniak, 2014; Pellegrino, et al., 2001), students' science understandings progressively built over time; their use of appropriate science concepts, as seen in Tables 5.1, 5.2, and 5.3, increased significantly with each iteration of the explanation. Students were able to move away from fragmented or disconnected ideas to make increasingly more connections among science ideas and build more meaningful relationships to develop more sophisticated understanding that moved toward an integrated understanding (Roseman et al., 2008). In other words, as students gained more experience in the practice of writing explanations, through a process of constructing an evolving explanation, and the synergy of various supports, they included a richer, more sophisticated discussion of scientific principles. This pattern occurred for all of the water quality measures explored in this study.

As Bransford and colleagues (1999) and Krajcik and Shin (2013) suggest, learning complex ideas take time and students can be supported to engage in such challenging undertakings when they work on a meaningful task that forces them to synthesize and use ideas. Devoting time in curricula where students work on meaningful tasks, in the form of iterative experiences (Fortus & Krajcik, 2011; NRC 2010) using supportive structures like the Explanation Framework (McNeill & Krajcik, 2011), can assist students to think more deeply about science ideas because they are synthesizing and using those ideas (Krajcik & Shin, 2013) in the same way as professional scientists. The multiple opportunities students received in this curriculum allowed them to revisit important ideas and assisted them to move away from understanding science ideas as bits of disconnected facts and to begin to organize their knowledge around core science ideas in much the same way that experts do (Chi, 2011; Hmelo-Silver & Pfeffer, 2004; Rottman, Gentner, & Goldwater, 2012). Just as with Pellegrino and colleagues (2001), Black (2003), and Krajcik & Czerniak, (2014) report, I believe practice and teacher feedback combined as critical components that contributed to the development of skill and expertise (Pellegrino et. al 2001) for students in this study. While the ideas of practice and feedback are not new, I believe that results from this study within the context of a much more complex explanation, this evolving explanation, not only illustrate the importance of practice and feedback, but additionally provide a rich example of how it fosters students towards greater synthesis when using new science ideas that result in more sophisticated understanding.

5.7.2 Discussion - Research Question Five: How does the practice of analyzing data/evidence and writing the first two iterations of an evolving explanation allow students to transfer their learning to new situations?

Perhaps the most significant finding of this portion of the study are results from comparing students' work for each water quality measure the first time they wrote about science concepts related to a specific water quality measure but after they were familiar with the explanation framework. Results of one-way repeated measures ANOVA of the weighted mean scores the first time students discussed science ideas from each water quality measure, but *after* they were knowledgeable in using the Explanation Framework was conducted showed a significantly effect for time (Table 5.4).

When students wrote about pH and temperature data (thermal pollution) they were novices to the practice of writing explanations. They also lacked connected science ideas and knowledge structures that prepared them to more fully utilize science ideas when incorporating new evidence and new science ideas into an existing explanation. When analyzing and initially writing about conductivity data and later dissolved oxygen data, students were more familiar with the framework; they had received teacher feedback related both to the framework and to pH and temperature water quality science ideas. When taking pH and temperature measurements for the first time, the students had no "hooks" (or limited hooks) to understand the phenomenon.

These two tests were part of the beginning of building a conceptual framework around water quality. Students were only beginning to develop a conceptual framework for water quality.

These results show that once students had initial experiences and then included new evidence related to new science ideas, they incorporated many more science ideas and relationships between those science ideas much more than in their earlier explanations. The first time students included conductivity (the 3rd water quality measure) and dissolved oxygen concepts (the 4th water quality measure) into their explanations the number of science concepts they included were significantly higher than the numbers included the first time students incorporated pH and temperature reasoning (the first two water quality measures). For conductivity and dissolved oxygen measures, students had a structure they could attach these ideas to. All of these comparisons were made after the Explanation Framework was introduced.

I conjecture that the large gains students' exhibited illustrate students' preparedness for future learning (Bransford & Schwartz, 2001). The synergistic instructional moves in the first two iterations of the explanation assisted students to progressively build knowledge structures that prepared them for extended learning, in other words transfer of learning. The context of this curriculum does not change; it is the water quality of a stream and human activities that impact it. The focus throughout is on the same phenomena: there are water quality factors that either support or are not conducive for freshwater organisms. The situations to determine the water quality of the stream, the various water quality measures, *do* change. Each water quality measure has science ideas. Analyses of students' scores on an end of the semester exam provide evidence that conductivity and dissolved oxygen concepts were not easier than pH and temperature concepts for students. Conductivity concepts may have been more challenging, in fact. The results suggest that students were able to transfer their learning, both related to constructing explanations and how to think more deeply about science ideas by making connections between them, as they gained more experience. I interpret these results to provide evidence that students are able to transfer their learning to new situations. They have developed a structure for thinking about and analyzing data using science ideas and it is now easier to connect to this structure.

5.8 Summary

Research shows that reasoning is the most difficult part of an explanation (Berland & Reiser, 2009; Gotwals & Songer, 2006; NRC 2007; McNeill & Krajcik, 2006). In order to reason, however, students must have an understanding of science ideas. In this chapter, I examined the development of students' science ideas across the four iterations of the evolving explanation to explore how students move towards developing more sophisticated understanding of those science ideas that may then be used as part of reasoning in the scientific explanation. I also explored if students were then able to transfer their learning to new situations (Bransford & Schwartz 2001).

CHAPTER 6

Reasoning: Connecting Science Ideas with Evidence

6.1 Overview of the Chapter

Reasoning consists of connecting science ideas to explain evidence. Chapters 5 and 6 work to tease apart reasoning into these components. In Chapter 5, I focused on the development of students' science ideas over four iterations of an explanation to see if they progressed towards building understanding of all of the relationship of those science ideas, that is part of the reasoning in a scientific explanation. In this part of the study, which is the focus of Chapter 6, I examine the connections that students make with those science ideas to their evidence as part of reasoning and in this way will respond to Research Questions Six through Nine. Through results discussed in Chapter 4, I determined that many students struggle to adjust claims in light of new, additional evidence. As such, in this chapter I also explore if there is a relationship between connections to evidence and/or science ideas in students' ability to adjust their claims over the process of writing four iterations of the explanation as new evidence emerges.

6.2 Problem Statement

Helping students to develop integrated understanding, where students identify more and more relationships between science ideas and also apply or connect those understandings to observations of the natural world assists students to explain phenomena and solve problems. Experts are able to understand and explain phenomena and work on solving problems because they have well-organized knowledge structures and are able to apply their understandings by connecting science ideas with observations. The reasoning portion of the *claim, evidence*, and *reasoning* framework is viewed as the most challenging for students (Berland & Reiser, 2009; Gotwals & Songer, 2006; NRC 2007; McNeill & Krajcik, 2006). Students make a justification, using science ideas, to explain why the evidence supports their claim; this is not an easy task for students. They need to provide a logical connection between evidence and science ideas. In the reasoning portion of an explanation, students should articulate, using science ideas, how their evidence is used to generate the claim, in the case of this study, a claim to answer to their question, "*How healthy is the stream for freshwater organisms?*" Although they go hand-in-hand, in essence then, the reasoning portion of an explanation consists of two parts: science ideas and the connecting of those science ideas to evidence. Figure 6.1 illustrates what a novice's reasoning or lack of reasoning may look like (a), an emerging learner's reasoning (b), and (c) an expert's reasoning. A novice (a) may have no connections of science ideas to evidence. An expert has fully connected science ideas with evidence, and with experience, an emerging learner's reasoning would fall somewhere in between.

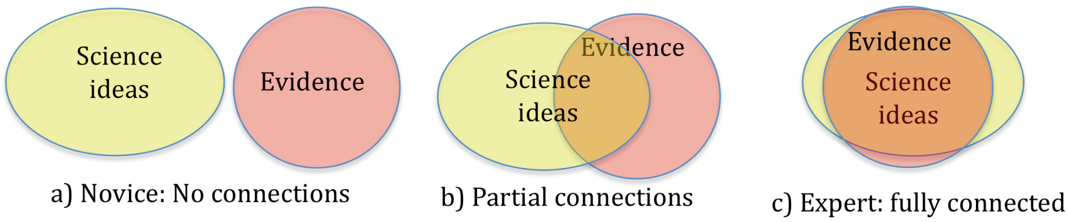


Figure 6.1: Reasoning: Using Science Ideas to Explain Evidence

Students should use science ideas to think about and then explain their evidence. Understanding of science ideas and connecting those science understandings to evidence may account for why students are so challenged with reasoning. This may be the key to whether or not students can *use* their knowledge. Generating a claim, then, should follow as part of a logical succession, although not necessarily linear, as learners and scientists often go back and forth from claim, evidence, and reasoning as they work towards sense-making. Students should use their science knowledge, knowledge in use, to generate a claim. In Chapter 5, I discussed students' understanding of science ideas across time; students' progress towards seeing more and more relationships among science ideas across the four iterations of an evolving scientific explanation was investigated. Students need to use this understanding to connect those science ideas to evidence and then generate an appropriate claim. One could argue, in fact, that reasoning consists of three components: science ideas, connecting those science ideas to evidence, and then generating an appropriate claim based on the science ideas and connections. Perhaps, when students can successfully do all of these, will they then possess organized, usable knowledge and thus, truly have integrated understanding.

6.3 Research Questions: Reasoning

The research questions examined in this chapter include:

6. How do students connect science ideas with evidence and are students able to make more connections to evidence over time?
7. Does the process of writing the first two iterations provide students with experience to make more connections among science ideas with evidence when writing about new evidence: Is there transfer?
8. How are the levels of understanding that students possess about science ideas related to the connections to evidence that students make over time?
9. What is the impact of students' understanding of science ideas and/or connections with evidence on their ability to adjust claims when faced with new evidence?

6.4 Data Sources and Data Collection

The reasoning and claim portions of each of the four iterations of the explanation for all students were used as data sources. Reasoning included both science ideas and connections to evidence. In addition to classroom discussion, students completed teacher prepared guide sheets, working with partners, as a support to assist them to connect science ideas with evidence. A portion of the guide sheet is presented in Figure 6.1. Throughout the iterative process, students received teacher feedback and gained experience. In explanations #3 and #4 students were to revise earlier work by incorporating teacher feedback. In addition, students were to incorporate new evidence into these iterations. A more complete discussion of the collection of data for the four iterations may be found in the data source section of Chapter 3, Methodology.

REASONING: explain and discuss results: Use scientific concepts from background information with your evidence (Test results and physical data) **What** do the results Mean? Standard. Are these results positive Or negative? Why? Consequences from background (examples) **Why** did you get these results? Incorporate the causes completely discuss/explain-		

Figure 6.2: Portion of an Explanation Guide Sheet for Student Notes

6.5 Data Analysis - Overview

A comprehensive concept map (See Appendices E-H) (Novak & Gowin, 1984), created by the researcher, represented all of the science ideas and the relationships between them. Three water ecology experts evaluated this concept map for scientific accuracy verifying that it contained all of the science ideas and all of the relationships. Next, the concept map was used to create a detailed rubric, using a base rubric for analyzing scientific explanations (McNeill & Krajcik, 2011) that included claim, evidence, and reasoning [11](See Chapter 3, Data Analysis, for further discussion).

An example from the pH portion of the rubric used to score the explanations is presented in Figure 6.2. Notice that reasoning is split into "science ideas" and "connections." Students earned one point for each accurate science idea. They earned zero for inaccurate ideas or if ideas were not present in their explanations. Results from students' science ideas are discussed in Chapter 5.

[11] The rubric also included rebuttal and action steps that are not discussed in this document.

Reasoning

__0__ Does not provide reasoning or provides inappropriate reasoning.

Provides all reasoning components: WHAT evidence means and WHY these results? Connects reasoning to evidence for each WQ test.

pH Science Ideas

__1__ Stream is acidic? Basic? Neutral? correct

__1__ Correct Standard –*most neutral a couple slightly basic (excellent or good – a couple fair)*

positive results:

__1__ Most organisms need neutral pH: will die

__1__ Ex: name of organisms and pH range needed

__1__ Ex. - product and pH from land-use run-off

__1__ Buffers – define

Connects pH science ideas to pH evidence

__0__ No connection* choose one*

__1__ Vague/partial connection*

__2__ Clear connection*

Figure 6.3: pH portion of Rubric related to Reasoning. Includes Science Ideas and Connections

Students also needed to connect their science ideas to their evidence as part of reasoning; both quantitative and qualitative data could be used as evidence. Qualitative data included observations in and near the stream related to potential causes of a specific water quality measure or possible positive or negative effects from that water quality measure. In order for students to make connections they needed to connect the specific evidence, both qualitative and quantitative, from their stream section with science ideas (see examples later in this chapter). Connecting science ideas with evidence meant students discussed their data within the context of their stream results. If students discussed science ideas without relating them to their evidence this was considered out-of-context, or decontextualized, with no connections. It would be similar to what Parten describes as parallel play with young children (1932); children might be sitting next to each other in a sandbox, for example, each playing, but not interacting with each other. Applying this notion to constructing reasoning as part of an explanation, students might report their evidence and then they might discuss science ideas, side-by-side, but never make any connections between them. Students earned zero points if they did not connect the science ideas with their evidence, one point if they made a vague connection or made only partial connections, and two points if there was a clear connection to evidence. In this thesis when the word connection is used in the context of reasoning, it will mean connection of science ideas to evidence. Examples from students' work are provided in the findings for research question one.

In addition to pH, science ideas and connections, the rubric included science ideas and connections for temperature, conductivity, and dissolved oxygen. The complete scoring rubric may be found in Appendix I. The rubric included possible points for complete claims that would reflect incorporation of all four pieces of evidence. Claims related to explanations that included two or three pieces of evidence had rubric points that reflected these. These claims rubrics are put together in one table in Appendix J.

6.6 Analyses and Findings for Each Research Question

The remainder of the chapter is organized as follows: I will consider each research question separately including how the research question was analyzed, the related findings, and examples from student work to illustrate the various findings. A section at the end of the chapter includes a discussion of each of the research questions.

6.6.1 Analysis and Findings of Research Question Six: How do students connect science ideas with evidence and are students able to make more connections to evidence over time?

Research Question Six explores both *if* students connect science ideas to evidence, the reasoning portion of an explanation, as well as if students make more connections over the course of four iterations of an evolving explanation. In order to investigate these, student connection scores from the rubric were used as the data source. A statistical analysis was performed that included ANOVA using a repeated measure design for each separate water quality measure. All four iterations of the explanation included pH and temperature data so all four scores were compared for each of these water quality measures. For the conductivity water quality measure, only Explanations #3 and #4 were compared. Additionally, dissolved oxygen was not utilized because students incorporated this water quality test only in the fourth and final iteration of the explanation. Crosswise comparisons for each water quality measure for each iteration were also performed.

The analysis of the results based on rubric (see Table 3.5) to determine if students connect science ideas to evidence and if those connections increased across the four iterations showed that a statistically significant difference occurred (Table 6.1) for all water quality measures over the four iterations. In other words, based on the rubric scores, the mean score increased after each iteration.

Table 6.1: ANOVA results showing changes in students' connections, science ideas to evidence, across an evolving explanation (n=51)

Explanation		M	SD	df	MS	F	Sig.
pH	Ex1	.24	.47	2.29	28.73	104.51	.000
	Ex2	1.18	.79				
	Ex3	1.53	.64				
	Ex4	1.71	.54				
Temp	Ex1	.27	.53	2.41	26.44	109.00	.000
	Ex2	1.25	.74				
	Ex3	1.59	.64				
	Ex4	1.69	.58				
Conductivity**							
	Ex3	1.51	.697	52		t=3.46	.001
	Ex4	1.75	.559				

**For Conductivity N=53.

Note. For pH and Temperature measurements, the ANOVA measurements were conducted using a Greenhouse-Geisser correction because Mauchly's test of spehericity showed that common variance scores across the four time points could not be assumed. Hence the degrees of freedom are not whole numbers.

Additionally, as shown in Table 6.2, pairwise comparisons for pH also indicated a significant difference at the $p < 0.05$ level for all pairings.

Pairwise comparisons made for Temperature across the four iterations, as shown in Table 6.3 followed a similar trend as pH, also indicating a significant difference at the $p < 0.05$ level for all pairings except between Explanations #3 and #4, perhaps an illustration of a ceiling effect.

Table 6.2: Results of Pairwise Comparisons: pH connections across an evolving explanation (n-51)

Time (I)	Time (J)	Mean Difference (I-J)
Ex1	Ex2	-.94*
	Ex3	-1.29*
	Ex4	-1.47*
Ex2	Ex1	.94*
	Ex3	-.35*
	Ex4	-.53*
Ex3	Ex1	1.29*
	Ex2	.35*
	Ex4	-.18*
Ex4	Ex1	1.47*
	Ex2	.529*
	Ex3	.176*

Table 6.3 Results of Pairwise Comparisons: Temperature connections across an evolving explanation (n-51)

Time (I)	Time (J)	Mean Difference (I-J)
Ex1	Ex2	-.98*
	Ex3	-1.31*
	Ex4	-1.41*
Ex2	Ex1	.98*
	Ex3	-.33*
	Ex4	-.43*
Ex3	Ex1	1.31*
	Ex2	.33*
	Ex4	-.10
Ex4	Ex1	1.41*
	Ex2	.43*
	Ex3	.10

Finally, a paired sample test indicated a significant difference (2-tailed) at the $p < .001$ level for conductivity for Explanations #3 and #4. Results may be found in Table 6.4.

Table 6.4: Paired Sample Test: Conductivity connections across Explanations #3 and #4 (n-53)

Time (I)	Mean	Standard Deviation
Ex3 - Ex4	-.245	.52

Below I present an example of a typical students' development of connections of science ideas with evidence. We now look at portions of Elise's temperature reasoning by examining her work in Explanations #1 through #3 with particular focus to explore the connections she's made of the science ideas to her evidence. Teacher feedback is also included.

Elise's Temperature Reasoning from her Initial Explanation #1, Ex1

As a class, student groups shared data. Students were then asked to write individually what they thought a scientist would write to answer the question, *"How healthy is the stream for freshwater organisms based on what we know now?"* We will see in her initial explanation, before the introduction of the explanation framework, Elise only presents a limit number of science ideas and therefore does not have many options of connecting science ideas to evidence. There are four possible causes and four possible consequences of thermal pollution. Below we see that Elise defines thermal pollution and that the stream does not have thermal pollution, but she does not move any further to explain what her evidence means (why it's positive and relate this to consequences) and why she thinks she obtained those results (discussion of the causes). Her response was scored with a zero for connections to evidence.

"Thermal pollution is abnormal increases in temperature. When we tested for temperature, we wanted the differences of each section to land in the excellent range (0-2 degrees Celsius change). Section 9 was in the 10 range, once we took the stream as a whole and found the difference. The number was around 4.5 degrees Celsius change, meaning it was in the good range, not having thermal pollution."

Elise's Temperature Reasoning from Explanation #2: After the introduction of the Framework, Class Discussion, and Scaffolded Guide Sheet

The teacher then introduced students to the explanation framework as well as a scaffolded guide sheet that included supports to assist students to construct an explanation. Students used this scaffolded guide sheet and worked with partners to take notes while the teacher moved from group to group to assist students. Students then constructed the second iteration of the explanation (Ex2). Some students revised their initial explanations and other students decided to start over. Next, is Elise's temperature portion of her second iteration (Ex2). This is after she has reported her evidence.

…. "The results for locations A, B, and C were (4.5, 3.9, 3,8 ^{0}C change) respectively. Our results for temperature difference fall into the good range, meaning there is no thermal pollution. Thermal pollution is an abnormal temperature increase in a body of water. One cause of thermal pollution is Erosion. This happens when the riverbank washes into the water and the water becomes muddy. The soil or other particles absorb the heat, then causing the water to heat up. Another cause of thermal pollution is when surfaces heat up. This is when roads, parking lots, and rooftops heat up, when the rain come in contact with the hot surface it heats up the rain, then eventually finds its way into a storm drain. These are just some of the causes of thermal pollution. Some of the main consequences of thermal pollution includes, fish dying. This occurs because fish need certain temperature ranges to live in. If it gets too hot, they cannot survive. Fish also need oxygen and warm water can hold less oxygen. Another main cause is animals can get sick; this can lead them to not having enough energy to compete for the natural resources they need to live. The reason we got higher than excellent temperature difference we think is because along the perimeter of the condos (apartments) is a paved sidewalk. This is an example of surfaces heating up, which could eventually increase the thermal pollution in our pond."

Elise has now included many more science ideas showing the relationships between these science ideas by including several causes and consequences of thermal pollution. What she has neglected to do, however, is to talk about those causes and consequences in the context of her data; she has simply reiterated what she had written in a background paper that she composed prior to data collection. Writing about these science ideas serves to promote her understanding of the science ideas, but these ideas could hold true for any fresh water body of water. These science ideas follow her evidence but are not integrated with it. She does make one connections of science to her evidence and that is in the second to last sentence where she discusses a paved sidewalk "*along the perimeter of the condos*" as a reason for "*higher than excellent temperature differences*." Overall though, Elise's explanation could be considered as vague connections so her explanation for temperature connections is scored one point (out of two).

Teacher Feedback for Elise's Explanation #2

The teacher provided feedback to Elise, shown below, to support her to integrate the science ideas with the evidence, in other words, to use the science ideas to explain the evidence. Below are portions of Elise's Explanation #2 followed by teacher comments that Elise was to use for revision as part of her Explanation #3.

Elise*: "Our results for temperature difference fall into the good range, meaning there is no thermal pollution. Thermal pollution is an abnormal temperature increase in a body of water."*

Teacher comment*: "Nice connection of science ideas!"*

Elise*: "One cause of thermal pollution is Erosion. This happens when the riverbank washes into the water and the water becomes muddy. The soil or other particles absorb the heat, then causing the water to heat up."*

Teacher comment*: "Good – now related this to section 9. Do you have particles – soil or algae. Are they heating up?*

Elise*: "Another cause of thermal pollution is when surfaces heat up. This is when roads, parking lots, and rooftops heat up, when the rain come in contact with the hot surface it heats up the rain, then eventually finds its way into a storm drain."*

Teacher comment*: "Good – now relate this to section 9. You have many surfaces that could heat up. What are the surfaces that can impact section 9 and why aren't they impacting it now?"*

Elise*: "These are just some of the causes of thermal pollution. Some of the main consequences of thermal pollution includes, fish dying. This occurs because fish need certain temperature ranges to live in. If it gets to hot, they cannot survive. Fish also need oxygen and warm water can hold less oxygen. Another main cause is animals can get sick; this can lead them to not having enough energy to compete for the natural resources they need to live. The reason we got higher than excellent temperature difference we think is because along the perimeter of the condos is a paved sidewalk."*

Teacher comment*: "Again – it's not the condos for your section…what about GH's (*the school's name) *parking lot, roof?"*

Elise*: "This is an example of surfaces heating up, which could eventually increase the thermal pollution in our pond."*

Teacher comment*: "Yes – lots of surfaces – not heating up now – why not?"*

Elise's Temperature Reasoning from Explanation #3: Revisions of Temperature based on teacher feedback

Below is a portion of Elise's temperature explanation where she has taken teacher feedback into account. I have underlined science ideas of causes as well as connections Elise has now made directly to her evidence.

"The result for locations A, B and C were (4.5,3.9,3.8 °C change) respectively. Our results for temperature difference fall into the good range, meaning there is no

thermal pollution. Thermal pollution is an abnormal temperature increase in a body of water. One of the problems of thermal pollution is animals can get sick; this can lead them to not having enough energy to compete for the natural resources they need to live. Another cause of thermal pollution is Erosion. This happens when the riverbank washes into the water and the water becomes muddy. The soil or other particles absorb the heat, then causing the water to heat up. We found algae in all three locations in section 9. This could be a potential issue in the stream concerning thermal pollution, because the algae then heats up causing the water to heat up. This does not affect our section right now because of the cold weather. Another cause of thermal pollution is when surfaces heat up. This is when roads, parking lots, and rooftops heat up, when the rain come in contact with the hot surface it heats up the rain, then eventually finds its way into a storm drain. We have many surfaces near section 9 that could heat up including the Greenhills rooftops, parking lots. Even though we had rain the day before this did not affect the temperature of our pond because of the cold weather. These are two main causes of thermal pollution that do not affect the temperature of our section right now. If we were to go and test for the temperature in July when it is hot outside, our numbers could drastically increase. Some of the main consequences of thermal pollution includes, fish dying. This occurs because fish need certain temperature ranges to live in. If it gets too hot, they cannot survive. Fish also need oxygen and warm water can hold less oxygen."

Elise takes into account the feedback provided by the teacher by addressing all of the edits. Her temperature reasoning now integrates science ideas and evidence to portray a progression towards strong reasoning. Her score is now 2/2 points for connections. There are only minor edits for the 4th iteration of the explanation, which are not included here.

6.6.2 Analysis and Findings of Research Question Seven: Does the process of writing the first two iterations provide students with experience to make more connections of science ideas with evidence when writing about new evidence: Is there transfer?

Research Question Seven explores transfer: Once students have had some experience do they connect science ideas more with evidence when writing about newly obtained evidence? Student "connection to evidence" scores from the rubrics (See Table 6.2) were used as the data source. This analysis used a repeated measure to compare the first time students connected science ideas to evidence, but after they were introduced to the explanation framework. This analysis compared pH and Temperature science connections from Explanation #2, Conductivity connections from Explanation #3, and Dissolved Oxygen connections from Explanation #4.

Throughout the iterative process, students received teacher feedback and gained experience.

When looking to see if students make more science connections to evidence when writing about new evidence after they have some experience, the results in Table 6.5 show a statistically significant difference of the means at the $p < 0.05$ level.

Table 6.5: Results of Repeated Measure Science Connections to Evidence - First time after introduction of explanation Framework (N=52).

First time after framework	Mean	SD	df	MS	F	Sig.
pH Ex2	1.17	.79	2.76	1.36	3.90	.024
Temp Ex2	1.25	.74				
Conductivity Ex3	1.50	.70				
Dissolved Oxygen Ex4	1.44	.73				

Note. For pH and Temperature measurements, the ANOVA measurements were conducted using a Greenhouse-Geisser correction because Mauchly's test of spehericity showed that common variance scores across the four time points could not be assumed. Hence the degrees of freedom are not whole numbers.

Exploring student connections the first time they made them with knowledge of the explanation framework, a pairwise comparison for these connections (Table 6.6) indicated a significant difference at the $p < 0.05$ level between the first time students made pH and temperature connections in Explanation #2, after they were familiar with the framework, compared with the first time they made conductivity connections in Explanation #3. For dissolved oxygen connections in Explanation #4, a statistically significant difference was seen between pH and dissolved oxygen links. Connections between dissolved oxygen and temperature, and between dissolved oxygen and conductivity were not statistically significant.

Table 6.6: Results of Pairwise Comparisons: Connections - First time after introduction of explanation framework (n=52)

Time (I)	Time (J)	Mean Difference (I-J)
Ex2	Ex2 Temperature	-.08
pH	Ex3 Conductivity	-.33*
	Ex4 Dissolved Oxygen	-.27*
Ex2 Temperature	Ex2 pH	.01
	Ex3 Conductivity	-.25*
	Ex4 Dissolved Oxygen	-.19
Ex3 Conductivity	Ex2 pH	.33*
	Ex2 Temperature	.25*
	Ex4 Dissolved Oxygen	.06
Ex4 Dissolved Oxygen	Ex2 pH	.27*
	Ex2 Temperature	.19
	Ex3 Conductivity	-.06

As well, there was no statistical significance between pH and temperature connections; these water quality tests were both written for Explanation #2. Figure 6.3 is another illustration of the results. Statistically significant increases are visible between pH and both conductivity and dissolved oxygen. Another large, statistically significant increase may be seen between temperature and conductivity.

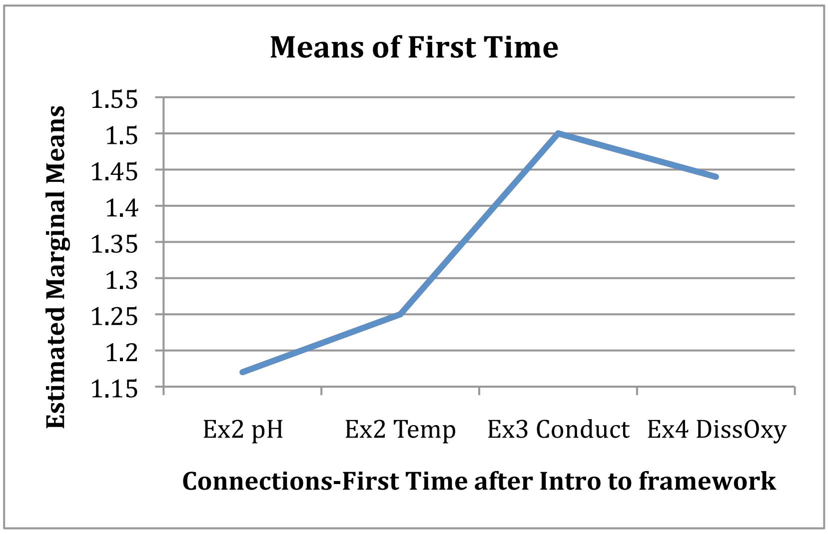


Figure 6.4: Connections: First time after introduction of explanation framework (n=52)

Below I present an example of a typical student's explanation. We now look at Maggie's science connections to Evidence for each of the water quality measures the first time she is incorporating them into her explanation after the introduction of the explanation framework. This incorporation includes pH and temperature for Explanation #2, conductivity for Explanation #3, and dissolved oxygen for Explanation #4. Because pH and temperature are both part of the first time students connected science to evidence after being introduced to the explanation framework they are included together here. The claim is also included because it provides a context.

Explanation #2: Maggie's First time connecting pH and temperature ideas with evidence.

"We have a pretty clean stream. *The reasons are that our pH was at around 7.5. That's a standard of excellent! Our temp. Difference standard was also good so our stream is clean.....We can tell that the water is fairly clean just by looking at the stream, there's no oil or other things you can see in the water. We did notice bubbles in the water though. One thing that probably helps the temp. difference is that our section has "cliffs" that help shade it. ....I think the reason we have such a clean stream is that Greenhills community members are very aware of the stream and try to take care of it."*

Maggie earned zero points, no connections, for connecting science ideas to evidence for both pH and temperature reasoning portions of the explanation in her first attempt after she was introduced to the explanation framework. She did not include science ideas of causes for each water quality measure nor consequences to freshwater organisms. She used her evidence as reasoning for pH and she used observations unrelated to the water quality measures as well. Next, we see her first attempts at connecting science ideas related to conductivity to new evidence.

Explanation #3: Maggie's First time connecting conductivity science ideas with new evidence.

"I think our conductivity was bad mostly because of all the leaves in the water. Dead leaves have a lot of Phosphorus and nitrogen in them, and its fall with most of the leaves off the trees by now. So that was a big factor, and the condo lawns seem very green. Believe it or not fertilizer has a lot of phosphorus and nitrogen in it, but the lawn already has all it needs. So the phosphorus and nitrogen gets washed into the stream.

Road salt can be a conductivity problem because it's salt, which is bad. I forgot to mention why conductivity is bad. Phosphorus and nitrogen feed algae, and algae feeds bacteria. Bacteria uses all the oxygen in the water and there is none left so it kills all the other organisms."

In her first attempt to use science ideas to explain her new evidence, conductivity data, Maggie included many more science ideas to explain her evidence than she did for pH and temperature. She was been able to transfer understanding: she included science ideas in the explanation and she also used those science ideas to explain her evidence. Her experiences with pH and temperature prepared her for the future learning (Bransford & Schwartz, 2001) of additional water quality measures. She earned both possible connection points for this part of the explanation. For the final iteration that included dissolved oxygen data for the first time, Maggie again connected science ideas with evidence to explain her data. She could have included more detail but, none the less, she made the connections. See below.

Explanation #4: Maggie's First time connecting dissolved oxygen ideas with evidence.

"Our most recent test was D.O. even though it was cold outside (warm/hot water holds less Oxygen) and raining (fast moving water traps Oxygen from the air) we still got a horrible D.O. result. When we test D.O. our result comes in a percent. Our percent was a small 61%, each percent fits into a standard. Our sections standard was fair, the second worst out of the four standards."

Learning complex ideas takes time and often occurs when students work on a meaningful task that forces them to synthesize and use ideas (Bransford, Brown, & Cocking, 2000; Krajcik & Shin, 2013). The research in this thesis supports these ideas and shows how they contribute to students' preparation for future learning.

6.6.3 Analysis and Findings of Research Question Eight: How are the levels of integrated understanding that students possess about science ideas related to the connections to evidence students make over time?

Two separate analyses were used to investigate Research Question Eight. Integrated understanding of science ideas was determined by developing a rubric from the concept map of the science ideas and relationships between those science ideas. (See the top of Table 6.2 in the rubric for pH science ideas and Chapter 5 for a thorough discussion of measuring integrated understanding of science ideas). First, a regression analysis using ANOVA was conducted for each water quality measure across time to see if science ideas impacted upon the amount of connections that students made across time, in other words to see if weighted scores for connections were dependent on weighted scores for science ideas for each explanation. Scores needed to be weighted because there were different numbers of science ideas for the various water quality measures. Table 3.3, in Chapter 3 shows the rubric for scoring explanations #1 and #2 that included pH and temperature ideas. The number of science ideas is included in the reasoning portion of the rubric (a comprehensive rubric for all water quality measures may be found in Appendix I). pH and temperature analyses were conducted for all four iterations of the explanation. Conductivity analysis was conducted for Explanations #3 and #4. Dissolved Oxygen was not included because students incorporated this water quality test only in the fourth and final iteration of the explanation.

For the second analysis, each iteration (Explanations #1, #2, #3 and #4) was looked at to see if the weighted scores for all of the connections were dependent on the weighted scores for all of the science ideas in that particular explanation. A simple regression was used that allowed statistical analysis to be completed with two variables (all connections and all science ideas). This helped to compensate for the limited sample size (N=58) in the study.

Table 6.7 reports the mean and standard deviations of connections and science ideas for each water quality measure for each iteration of the explanation.

Table 6.7: Mean Scores for Science Understanding impact Connections to Evidence Over Time?

	pH		Temperature		Conductivity		
Explanation	M	SD	M	SD	M	SD	N*
#1Connections (B)	.21	.45	.25	.51	--	--	57
Science ideas	1.11	.80	1.18	.95	--	--	
#2 Connections(A)	1.14	.79	1.21	.77	--	--	57
Science ideas	2.46	1.34	3.18	2.06	--	--	
#3 Connections	1.52	.63	1.55	.65	1.43	.75	58
Science ideas	4.05	1.58	5.12	2.60	3.98	2.17	
#4 Connections	1.72	.53	1.70	.58	1.75	.55	53
Science ideas	4.79	1.38	6.36	2.39	5.42	1.77	

B=Before introduction of explanation framework. A=After introduction of the explanation framework. *N=Number of Students

Looking at each water quality measure separately across all four iterations of the explanation using multiple regression analysis in Table 6.8, the findings suggest that connections are, in fact, dependent on the level of understanding of science ideas. All variables showed to be statistically significant for each water quality measure. Results indicate that as students develop more understanding of the relationships between science ideas for a particular water quality measure, they are able to make more connections to the evidence provided. For pH and temperature for Explanations #2, #3, and #4, the results suggest a statistically significant difference at the $p<.0001$ level. According to the adjusted R^2 values in Table 6.8, the best predictors of students' understanding of water quality were the fourth iteration of pH measurements and explanations (56.5% of the variance and β coefficient of 0.757) and the third iteration of temperature measurements and explanations (38.9%) (closely followed by the fourth iteration 38.2%) with almost identical β values of 0.630. Introduction of the first water conductivity measurements and explanation predicted a moderate amount of variance \ (38.3%) of students' understanding of the stream's water quality with a β coefficient of 0.628.

Table 6.8
Summary of Multiple Regression Analysis to see whether Connections to Evidence are Impacted by Science Understanding for each Water Quality Measure

Variable	B	SE(B)	ß	t	Sig. (p)	Adjusted R^2
pH Explanations						
#1	.190	.072	.334	2.632	.011	.096
#2	.370	.063	.621	5.881	.000	.375
#3	.283	.037	.714	7.626	.000	.501
#4	.293	.035	.757	8.271	.000	.565
Temp Explanations						
#1	.210	.067	.390	3.139	.003	.137
#2	.222	.041	.592	5.452	.000	.339
#3	.159	.026	.632	6.106	.000	.389
#4	.151	.026	.627	5.753	.000	.382
Conduct Explanations						
#3	.217	.036	.628	6.033	.000	.383
#4	.119	.040	.382	2.954	.005	.129

Explanations #1 & #2: N=57; Explanation #3, N=58; Explanation #4, N=53.

In order to look for trends, an additional analysis was conducted to look at each explanation that included all of the water quality measures for that explanation. A regression analysis grouped the weighted scores for connections and the weighted scores for science ideas (Table 6.9) for each iteration of the explanation. According to the adjusted R^2 values in Table 6.9, the best predictor of students' understanding of water quality was the third explanation that included pH, temperature and conductivity (63.8% of the variance and ß value of 0.803). When the fourth explanation included dissolved oxygen with pH, temperature and conductivity, this explanation predicted 54% of the variance of students' understanding of the local stream water quality with a ß value of 0.741.

Table 6.9
Summary of Regression Analysis to see whether Connections to Evidence are Impacted by Science Understanding for each Iteration of the Explanation

Variable	B	SE(B)	ß	t	Sig. (p)	Adjusted R^2	N
Explanation #1 pH/Temp (before)	.086	.024	.429	3.522	.001	.169	57
Explanation #2 pH/Temp (after)	.120	.015	.727	7.846	.000	.520	57
Explanation #3 pH/Temp/Conduct	.059	.006	.803	10.076	.000	.638	58
Explanation #4 pH/Temp/Cond/ Dissolved Oxygen	.041	.005	.741	7.879	.000	.540	53

N=number of students.

These results confirm the earlier results where connections and science ideas were compared separately for each water quality measure over time, suggesting that connections are dependent on understanding of science ideas. If we look back at feedback that Elise obtained from the teacher after constructing Explanation #2 (see **Explanation #2 with Teacher Feedback** above**)** one can see how that feedback supported Elise to both develop understanding of science ideas and make connections.

6.6.4 Analysis and Findings of Research Question Nine: What is the impact of students' understanding of science ideas and/or connections with evidence on their ability to adjust claims when faced with new evidence?

To investigate Research Question Nine, scores from science ideas, connections, and students' claims were utilized. Data were analyzed using multiple regression. First, looking solely at the final explanation, Explanation #4, all of the weighted connections were combined and all of the weighted science ideas were combined to create two variables. These were compared with the final claim that students made which was based on all the evidence from water quality data that was collected in four episodes over the six-week period. Next, for each explanation, weighted connections and weighted science ideas for each water quality measure (pH, temperature, conductivity, and dissolved oxygen) were assigned separately: each was a different variable. This provided insight into which variable, for each iteration, was most predictive of the claim. However, it also provided a constraint because there were many variables with limited sample size.

Research question four seeks to gain insight into what students base their claims on: Are students' claims dependent on their understanding of science ideas? Are claims dependent on connections of those science ideas to evidence?

Looking at students' final iteration, Explanation #4, that included all four water quality measures as well as the final claim that was to take into account evidence from all of these measures, a regression was conducted. The sum of all of the weighted connections and the sum of all of the weighted science scores were used as two separate variables to explore which variable was more predictive of claims. Results are illustrated in Table 6.10.

Table 6.10
Regression Analysis to explore, “What do Ss Base Claims on – Connections or Understanding of Science Ideas?”

Variable	B	SE(B)	ß	t	Sig. (p)	Adjusted R^2
Explanation #4: *Connections: All Water tests	4.281	3.728	.219	1.148	.256	.145
Explanation #4: *Science Concepts: All Water tests	.250	.205	.233	1.219	.229	

*Connections and Science Concepts were weighted. N=53.

The results suggest no indication that either connections or science ideas are predictive of claims that students make; neither is statistically significant. The adjusted R^2 value (14.5% and relatively low β coefficient values of 0.219 and 0.233) is consistent with the data in Table 6.8 which showed that when water conductivity was included in the fourth iteration of measurements, this resulted in a low prediction of students’ understanding of the water quality of the stream (12.9%).

So on what *do* students’ base their claims? To further explore this question weighted scores for science ideas, connections, and claims were used and a multiple regression was conducted for each of the four iterations of the explanation. Table 6.11 summarizes descriptive statistics for each of the iterations of the explanation.

Table 6.11
"On what do Students Base their Claims?"

Variable	Mean	Std. Dev	N
Explanation #1			
Claims1	178.42	137.91	57
pH connections1	1.26	2.716	57
Temp connections 1	1.47	3.060	57
pH science ideas1	23.21	16.689	57
Temp science ideas1	16.46	13.261	57
Explanation #2			
Claims2	307.89	96.135	57
pH connections 2	6.84	4.735	57
Temp connections 2	7.26	4.639	57
pH science ideas2	51.58	27.800	57
Temp science ideas2	44.46	28.877	57
Explanation #3			
Claims3	242.07	113.737	58
pH connections 3	6.07	2.512	58
Temp connections 3	6.21	2.614	58
Conductivity connects3	5.72	3.008	58
pH science ideas3	85.09	33.244	58
Temp science ideas3	71.69	36.345	58
Conduct science ideas3	71.69	39.102	58
Explanation #4			
Claims4	273.74	103.604	53
pH connections4	5.15	1.598	53
Temp connections4	5.09	1.724	53
Conductivity connects4	5.26	1.654	53
DissOxygen connects4	4.30	2.162	53
pH science ideas4	100.64	28.934	53
Temp science ideas4	89.02	33.413	53
Conduct science ideas4	97.47	31.856	53
DissOxygen science	*	*	53

*Dissolved oxygen science concepts not added because of the limited sample size.

Results from the multiple regression analysis (Table 6.12) show that for Explanation #1, pH science ideas was most predictive of students' claims; pH science ideas is the only variable that indicates statistically significant results (see bolded number on the table). For Explanation #2, temperature connections was most predictive of students' claims; it was the only statistically significant variable.

Table 6.12
Summary of Multiple Regression Analysis using weighted scores. "On what do Students Base their Claims?" Dependent Variable: Claim

Variable	B	SE(B)	ß	t	Sig. (p)
Explanation #1 (N=57)					
pH connections1	-3.287	7.813	-.065	-.421	.676
Temp connections1	2.455	6.956	.054	.353	.726
pH science ideas1	3.743	1.169	.453	3.201	**.002**
Temp science ideas1	-.255	1.519	-.025	-.168	.867
Adjusted R^2=.130					
Explanation #2 (N=57)					
pH connections2	1.719	3.401	.085	.505	.615
Temp connections2	7.879	3.556	.380	2.215	**.031**
pH science ideas2	-.032	.613	-.009	-.052	.959
Temp science ideas2	.109	.550	.033	.199	.843
Adjusted R^2=.140					
Explanation #3 (N=58)					
pH connections3	17.401	7.264	.384	2.396	**.020**
Temp connections3	-2.336	7.152	-.054	-.327	.745
Conductivity connects3	10.222	5.702	.270	1.793	.079
pH science ideas3	-.037	.627	-.011	-.059	.953
Temp science ideas3	-.559	.480	-.179	-1.165	.250
Conduct science ideas3	.740	.446	.254	1.660	.103
Adjusted R^2=.311					
Explanation #4 (N=53)					
pH connections4	29.482	13.302	.455	2.216	**.032**
Temp connections4	-23.123	12.019	-.385	-1.924	.061
Conductivity connects4	3.086	9.797	.049	.336	.739
DissOxygen connects4	8.328	7.604	.174	1.095	.279
pH science ideas4	-.198	.828	-.055	-.239	.812
Temp science ideas4	1.067	.558	.344	1.914	.062
Conduct science ideas4	.239	.557	.073	.429	.670
*DissOxygen science					
Adjusted R^2=.200					

*Dissolved oxygen science concepts not added because of the limited sample size.
Bold=Statistically Significant

In addition to pH and temperature connections and science ideas, conductivity connections and science ideas were added to Explanation #3. For Explanation #3, pH connections was most predictive of students' claims as pH was the only variable that was statistically significant. It should be noted that pH and temperature results indicated that the water quality of the stream was excellent for freshwater organisms, but results from the third piece of evidence, conductivity, indicated poor results (too many dissolved solids) for freshwater organisms. This represented evidence that was contrary to students' current thinking; students needed to re-think their current claim about the health of the stream and adjust it in light of this new evidence.

Finally, as seen in Table 6.12, for Explanation #4, pH connections was most predictive of students' claims. Dissolved oxygen connections were added for this analysis, but because of the limited sample size (n=53), dissolved oxygen concepts were not included.

6.7 Discussion

The research reported in this portion of the study focuses on the reasoning portion of the explanation framework. When students work to construct explanations to understand phenomena they need to use science ideas to explain their evidence. This is the reasoning portion of an explanation. Research shows that reasoning is the most challenging for students (Berland & Reiser, 2009; Gotwals & Songer, 2006; NRC 2007; McNeill & Krajcik, 2006). A major condition of reasoning is to understand causal relationships (NRC, 2007). Students conducted various water quality measures and obtained both quantitative and qualitative data and needed to analyze and interpret their results by using science ideas related to causes and consequences related to each water quality measure within the context of their stream. This included the impact of these measures on organisms in a local stream. Below I discuss findings of each Research Question Six through Nine.

6.71 Discussion for Research Question Six: How do students connect science ideas with evidence and are students able to make more connections to evidence over time?

Most students made no connections between science ideas and evidence initially. That means they did not include any reasoning in their initial attempts at constructing explanations prior to an introduction of the explanation framework. This makes sense, as students were novices. Most of these students did not include any science ideas that could be connected to evidence; they simply reported evidence, if they even did that. They had not yet developed knowledge structures related to the science ideas or the practice of constructing an explanation. They had not yet developed integrated understanding of science ideas to help them make sense of ideas to explain the phenomena (Fortus & Krajcik, 2011; Kali, Linn,& Roseman, 2008; Hmelo-Silver, & Pfeffer, 2004; NRC 2000); they held bits of disconnected information.

Once introduced to the framework of claim, evidence, and reasoning (McNeill & Krajcik, 2011) however, several patterns emerged. Some students still included limited science ideas and no connections to evidence. Some students used a circular argument that used data for both evidence and reasoning. For example, that pH was neutral with a pH of 7 and the reason it was neutral was because it had a pH of 7. Another pattern that emerged included students who reported evidence and discussed science ideas but never integrated them, similar to parallel play (Parten, 1932); their evidence text and science ideas were side-by-side but they never made any connections between them. These students were clearly working towards developing understandings with their understanding of science ideas ranging from much less sophisticated to more sophisticated, but they were written "out of context" as they were not written in the context of their evidence. Perhaps the explanation framework that supported them to explain phenomena also, initially at least, impeded students because their focus was on the structure of claim, evidence, and reasoning that they viewed as separate pieces. The framework, however, provided support for students to construct explanations to explain phenomena (McNeill & Krajcik 2011). Without the support of the framework the students would not have been able to engage in this complex task (Quintana, et al 2004). As students gained more experience with the framework many of them began to understand there was flexibility and that science ideas should be integrated with evidence.

The teacher played an important role to help these students by providing individual feedback as well as incorporating classroom and small group discussions about using science ideas to explain the evidence. Written feedback may have provided students with the "ongoing nudging" (NRC 2007, p. 287) that encouraged students to reflect on and more thoughtfully articulate ideas. When students are provided with formative feedback designed to assist them to improve the quality of their work, their understanding improves (Black, 2003; Bransford, et al,. 2000; Pellegrino, et al., 2001). The teacher in this study viewed herself as a coach who utilized intentional strategies to foster students towards optimal performance (Bransford, et al,. 2000). As Krajcik & Czerniak (2014) suggest, the various types of feedback provided to these students supported them to think more deeply. It served to ask thought-provoking questions, assisting students to think about causal relationships, and encouraging students to elaborate on their ideas.

Using these supports and knowing that understanding develops over time (NRC, 2013; Fortus & Krajcik, 2011; NRC 2010; NRC 2000; Nelson & Hammerman, 1996), the four iterations of the evolving explanation provided students with experience and time to develop deeper understanding of the science ideas as well as see more relationships between those ideas and then apply those understanding by connecting them to their evidence. The teacher provided students with several scaffolds to support students. These included introducing the claim, evidence, and reasoning framework, class discussion, and written feedback. The statistically significant results indicate that the use of these synergistic scaffolds (McNeill & Krajcik, 2009; Quintana, et al., 2004; Tabak, 2004) worked together to support students and, as a result, they were able to make more and more connections throughout the four iterations of the explanation.

6.7.2 Discussion for Research Question Seven: Does the process of writing the first two iterations provide students with experience to make more connections of science ideas with evidence when writing about new evidence: Is there transfer?

A goal of K-12 education is that students transfer their learning to new situations (Bransford & Schwartz, 2001; NRC 2000). The work in this study provides evidence that in school, prior academic learning can support students in future learning. The findings indicate that experiences to explain stream phenomena related to pH and temperature data (the first two water quality measures) prepared students for future learning (Bransford & Schwartz, 2001) or transfer for water quality measures that were performed later in the water study. These water quality measures included new science ideas. Students use of science ideas to explain conductivity and dissolved oxygen evidence, when incorporating these data into their explanation of the health of the stream the first time (conductivity in Explanation #3 and dissolved oxygen in Explanation #4) showed statistically significant increases compared to students' first time use of science ideas to explain pH in Explanation #2). Another large, statistically significant increase was seen between temperature (Ex2) and conductivity (Ex3). Students did not connect science ideas to evidence much, early when investigating and explaining the health of the stream, but they did later when performing different water quality measures after receiving teacher feedback, gaining experience in constructing explanations, and benefitting from class discussion. In general, students needed a great deal of support early on in the learning process. The teacher verbally "coached" students (NRC, 2000, p.177) working to support them to think more deeply by making suggestions, asking thought-provoking questions, and encouraging students to elaborate on their ideas (Krajcik & Czerniak, 2014). She did this through written feedback as well (NRC 2000; Pellegrino et.al 2001). Students were then able to apply what they learned when working to make sense of new science ideas and connect these to new evidence. This research then, extends the work of Bransford & Schwartz 2001). The work in this study provides evidence that earlier academic learning can support students in future learning. Students were developing knowledge structures, both related to science ideas and to constructing explanations, when learning about the first two water quality tests that allowed them to apply their understandings to new situations; this made new learning easier (NRC, 2001).

6.7.3 Discussion for Research Question Eight: How do the levels of understanding that students possess about science ideas relate to the connections to evidence students make over time?

Results indicate that as students develop an understanding of more of the relationships between science ideas for a particular water quality measure, they are able to make more connections to evidence. Two different analyses support these findings suggesting that connections are, in fact, dependent on understanding science ideas. All variables showed to be statistically significant for each water quality measure. Reasoning is the most challenging aspect of explaining phenomena (Berland & Reiser, 2009; Gotwals & Songer, 2006; NRC 2007; McNeill & Krajcik, 2006) because one challenge is for students to use science ideas when discussing evidence. In order to use science ideas, however, one has to have understanding of those science ideas; the more developed that understanding is (the more relationships students make between those ideas) the more connections they can then make to evidence. This is what Gotwals and Songer (2006) suggested as they found an interaction between domain specific knowledge and reasoning. In this case science ideas are related to water quality and people's impact on natural systems (See Figure 3.1 in Chapter 3), and connecting those with evidence from a local stream. In order for this to occur, though, it is imperative that students understand the causal relationships (NRC 2007) of the various water quality measures obtained. Students needed to provide a logical connection between evidence and science ideas. The findings in this study suggest that an evolving explanation where students revisit ideas, both conceptually related to science ideas and in the practice of constructing explanations, assisted them to more thoroughly provide connections between evidence and science ideas and the specific context of the phenomenon. This is a complex undertaking and one that research shows is the area where students struggle (Berland & Reiser, 2009; McNeill & Krajcik, 2006). Learning complex ideas takes time often occurs when students work on a meaningful task, like an ongoing process of constructing an explanation as new evidence is obtained, that forces them to synthesize and use ideas (Krajcik & Shin, 2013, Bransford, Brown, & Cocking, 2000). As Vygotsky (1986) suggested, learning occurs in social context and developing understanding of ideas is an emergent process. The iterative process of the evolving explanation provides students with multiple opportunities and with different contexts, just what is suggested in the New Framework for K-12 Science Education (2014). Similarly, understanding of and use of science and engineering practices doesn't develop with single exposures. Practices need to be used in multiply contexts (NRC, 2014), as they are in this study. Using the practice of developing the explanation, blended with helping students see patterns, and cause and effect, facilitates them to move away from understanding science ideas as bits of disconnected facts towards organizing their knowledge around core science ideas in much the same way that experts do (Chi, 2011; Hmelo-Silver & Pfeffer, 2004; Rottman, Gentner, & Goldwater, 2012). But if those understandings are truly integrated students should be able to generate appropriate claims. This hypothesis leads to research question nine.

6.7.4 Discussion for Research Question Nine: What is the impact of students' understanding of science ideas and/or connections on their ability to adjust claims when faced with new evidence?

Research question four seeks to gain insight into what students base their claims on. When looking at the final iteration of the explanation that included all of the evidence from four different water quality measures, neither connections nor science ideas had a statistically significant effect. The results suggest no indication that connecting science ideas to evidence or understanding of science ideas is predictive of claims that students make. Looking at each explanation separately there was no pattern that emerged, other than that students often failed to incorporate results from the 3rd and 4th water quality measures into their claims, even if they discussed them in the explanation. For Ex1 students' claims were most often generated from pH science ideas where as for Ex2 students' claims emerged from temperature links. When conductivity was added to the explanation, in Ex3, students' claims were generated from pH links. Finally, in Ex4, that included all data, students' claims emerged from pH links.

Does this imply that students, in fact, did not develop knowledge structures or were not successful in transferring their learning to new situations? Generating claims is thought to be relatively easy for students (Berland, & Reiser, 2009; McNeill & Krajcik, 2011; McNeill & Krajcik 2007; McNeill et al 2006). But when anomalous data are generated it becomes much more challenging (Chinn & Brewer 1993, 1998; Kuhn, 1996). Looking back to work reported in Chapter 4 can remind us of the progression of students' claims. Table 4.2 (repeated below from Chapter 4) illustrates various patterns that emerged when looking more closely at student claims.

Table 4.2: *Categories: Patterns of Claims found From Students' Evolving Explanation*

1. No claim	2. Attempted Claim	3. Vague claim	4. Partial claim	5. Complete claim
Student discussed the various data but never generated a claim	• Inappropriate claim (standards didn't match evidence, standards didn't match claim) • Contradictions in the claim • Claim emerged from only one test or the claim did not reflect the new evidence • Separate claims – no synthesis	Student may have talked about the "health" of the stream but did not utilize a standard nor include anything about organisms Student only talked in very general terms	Synthesis – Student made an appropriate claim: Student adjusted the claim as new evidence emerged but only included either the water quality standard OR a statement about organisms	Synthesis – Student made an appropriate claim: Student adjusted the claim as new evidence emerged and included both a water quality standard AND a statement about organisms

When evidence was consistent (two pieces of water quality data that were both positive) and once the explanation framework was introduced 80% of students made appropriate claims. These results may be seen in Figure 4.10 (repeated below from Chapter 4). The categories from Table 4.4 are seen on the far right side of the graph. The graph illustrates that, for Explanation #2, 36 students developed complete, appropriate claims while 10 additional students had appropriate claims, but they were not complete. These results are consistent with the situations typically described in the science education literature that show claims to be the most accessible part of explanations (Berland, & Reiser 2009; McNeill & Krajcik, 2011; McNeill & Krajcik 2007; McNeill et al 2006). In addition based on the two pieces of evidence the "claims were logically bound by the evidence provided", similar to what Berland (2009. p.22) and colleagues found. pH and temperature results had similar, positive results. These were the first two pieces of evidence obtained and students wrote an explanation based on these two pieces of evidence that showed excellent or good water quality for organisms. I found, however, that when new, conflicting evidence was obtained and incorporated into the explanation, as was the case for conductivity data that reflected poor results (too many dissolved particles), the percentage of students making appropriate claims decreased from 80% to 40%.

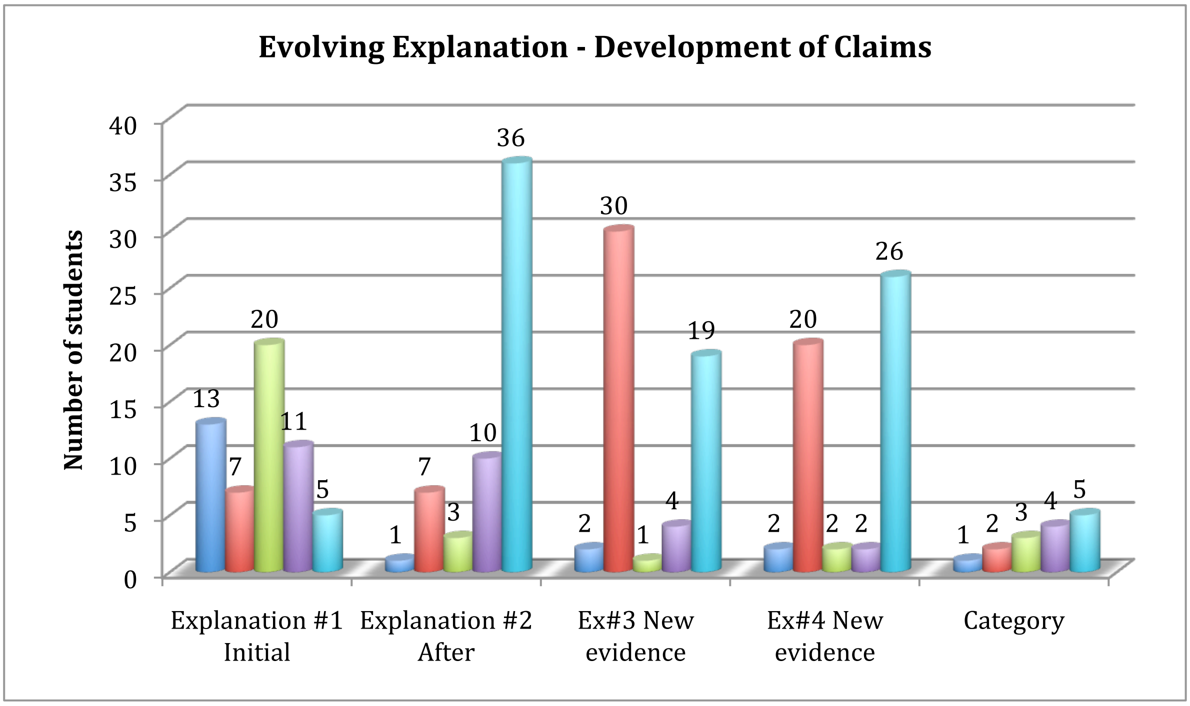


Figure 4.10: Progression of Claims in an Evolving Explanation

This is visible in Figure 4.4 for Explanation #3. Students needed to examine if their claim accounted for all available evidence (Duschl, 2007; Sampson & Clark, 2006), revise and/or reinterpret their findings based on the new evidence (Nature of Science Matrix, NGSS Appendix G, 2013) each time new data were obtained and analyzed. This third piece of evidence was inconsistent with the initial claim. Many students did not adjust their claims, even with various teacher supports. Some students included separate, compartmentalized claims. Other students ignored the new evidence, even those who set a context for the additional evidence. Some attempted, but struggled to develop a claim that incorporated the new evidence. Did students ignore anomalous data, as Chinn and Brewer found (1993, 1998), or struggle to let go when "adapting to new situations" as Bransford and Schwartz found (2001), or did they need to engage in more metacognitive processes (NRC, 2007) to rethink their claims as Choi and colleagues suggest (2011)? Scientists themselves, as Kuhn (1996) states can be challenged in making a paradigm shift in the face of anomalous data. Why should this be different for young learners? This will be further discussed in the conclusion chapter (Chapter 7) and has already been discussed in Chapter 4, but I offer a few thoughts below.

I speculate that many of these grade 7 students have never experienced exploring a phenomenon that is so complex. Many students do not have classroom experiences where they engage in writing explanations, yet alone working to explain such a complex phenomena. Just as data scientists might collect, the data students' collected in this study was not cut-and-dried. Students needed to negotiate four pieces of evidence from four completely different water quality measures into one claim about the overall health of the stream for organisms. This is not an easy task.

Even though this was a complex and challenging undertaking, many students, almost half, were successful at adjusting their claims. This suggests that these students developed knowledge structures around ideas related to the practice of constructing *scientific explanations*, the crosscutting concept of *cause and effect*, and disciplinary core ideas that blended science ideas from *Earth and Human Activity*, and *Ecosystems: Interactions, Energy, and Dynamics* (NGSS, 2013; NRC 2012; also see Appendix A). They were able to align their claims with evidence that was connected to science ideas. They moved far along the path from novices towards expertise. The data, I believe, suggest that all students in fact, made great strides towards developing integrated understanding; they increased in their development of the understanding of science ideas (Chapter 5) and in their reasoning: their connections of science ideas to evidence. The challenge for about 50% of the students, however, was to align their claims when faced with anomalous data that contradicted their previous claims. This study shows that they are moving along the pathway from novices towards expertise but their ideas are not fully aligned. What additional strategies teachers can incorporate to support these types of students is one area for additional study.

6.8 Summary

When initially working to explain phenomena most students used little, if any science ideas, and therefore did not incorporate reasoning, the connecting of science ideas to evidence. An iterative process where students constructed one explanation, an evolving explanation, through four iterations as more data was collected from a complex phenomenon over the course of six weeks, provided students with experiences to develop knowledge structures about related science ideas and about the practice of constructing explanations. Various scaffolds utilized by the teacher worked together to support students in this complex undertaking. The research reported in this chapter indicates that students became much more proficient at making connections of science ideas to evidence over time for a particular water quality measure and were then able to transfer that learning to make more connections to science ideas when investigating a new water quality measure that included both new evidence and new science ideas; they made more connections to science ideas the first time when they explained later water quality measures than when explaining earlier water quality measures.

Additionally, as discussed in Chapter 5, the level of students' science understandings, which also evolved over time, impacted the amount of connections students made to evidence over time. Students' claims, which should have also evolved as new evidence was obtained, evolved to reflect all of the evidence a little less than 50% of the time. Claims often only reflected evidence obtained early in the water quality investigation.

One could argue that reasoning consists of three components: science ideas, connecting those science ideas to evidence, and then generating an appropriate claim based on the science ideas and connections. Perhaps, when students can successfully do all of these, will they then possess organized, usable knowledge and thus, truly have integrated understanding. Findings from this study suggest that students in these classes are well on their way to developing integrated understanding as indicated with seeing more and more relationships between science ideas and more often connecting those ideas with evidence. Other indications, however, specifically using those understandings to develop an appropriate claim, still remain a challenge for many students.

CHAPTER 7

Conclusion

7.1 Overview of the Conclusion Chapter

Research presented in this thesis was designed to tease apart various components of scientific explanations to deeply explore these separate components. As such, this thesis was set up to report and discuss findings of these separate components within three different chapters. Various research questions were presented, data were analyzed and discussed, and the research questions were answered in each of the results chapters. In Sections 7.3, 7.4, and 7.5 of this conclusion chapter, I recap the research questions discussed in Chapters 4, 5, and 6, and summarize the findings for each. I then tie all of these separate pieces together to discuss the results as a whole. Following this, I discuss how findings from this work can contribute to the field of science education research and practice. Implications for research and for teaching are discussed. I conclude the chapter by sharing some limitations of the study.

7.2 Problem Statement

This thesis documents the process of fifty-eight, 7th grade students constructing one explanation, termed evolving explanation, through multiple iterations, as new evidence was obtained. The study is concerned with supporting students to develop integrated understanding through building a more sophisticated explanation over time. This research explored if each iteration helped students delve deeper into science ideas, thereby assisting them to organize their knowledge around core concepts to develop a more integrated understanding.

Based on research conducted in this study, I argue that using an evolving scientific explanation within a 3-dimensional learning environment facilitates students' towards development of integrated understanding. Students worked to develop knowledge structures across time that, like experts, allowed them to apply those understandings to explain a complex phenomenon and be prepared for future learning.

7.3 Claims: Research Questions and Summary of Findings

Chapter 4 looked exclusively at research questions related to claims. Various pathways were identified that students moved through towards complete, accurate claims including the challenges they overcame during the process. Additionally, challenges faced by students who were not able to make accurate claims were documented.

Three research questions were explored. Table 4.2, repeated from Chapter, 4 was developed to articulate the types of claims that students generated into five categories. These categories assisted in addressing all three research questions and the figure is included here as a reference.

1. No claim	**2. Attempted Claim**	**3. Vague claim**	**4. Partial claim**	**5. Complete claim**
Student discussed the various data but never generated a claim	• Inappropriate claim (standards didn't match evidence, standards didn't match claim) • Contradictions in the claim • Claim emerged from only one test or the claim did not reflect the new evidence • Separate claims – no synthesis	Student may have talked about the "health" of the stream but did not utilize a standard nor include anything about organisms Student only talked in very general terms	Synthesis – Student made an appropriate claim: Student adjusted the claim as new evidence emerged but only included either the water quality standard OR a statement about organisms	Synthesis – Student made an appropriate claim: Student adjusted the claim as new evidence emerged and included both a water quality standard AND a statement about organisms

Table 4.2: *Categories: Patterns of Claims found From Students' Evolving Explanation*

7.3.1 Claims - Research Question One: How do students adjust their claim as new evidence emerges?

Using the various categories presented in Table 4.2, I summarize results from each of the four iterations of the evolving explanation below.

<u>Explanation #1</u>: The first iteration (Ex#1*)* took place after students collected pH and temperature data but prior to their introduction to the explanation framework

of claim, evidence, and reasoning (McNeill & Krajcik 2011). Both water quality results were positive. As students were unfamiliar with explanations this served as a baseline with five students generating complete claims, 11 students making partial claims, 20 making vague claims. Another seven students attempted claims but there were problems and 15 students made no claim. A graph of the results may be found in Chapter 4, Figure 4.3.

<u>Explanation #2</u>: The second iteration (Ex2) results, after the introduction of the explanation framework, indicated that 80% of students generated appropriate claims. Evidence was consistent: two pieces of water quality data that were both positive. Three students made vague claims, seven attempted claims but had problems, and one student made no claim. Results are graphed in Chapter 4, Figure 4.5.

<u>Explanation #3</u>: This iteration of the explanation was written after obtaining new evidence. Students needed to reflect on all three pieces of evidence, two of which were excellent or good – pH and temperature - and the third piece of evidence that was poor - conductivity. Students experienced challenges in adjusting claims when they needed to integrate new, contradictory evidence. The percent of students generating appropriate claims decreased from 80% in Explanation #2 to 40% in Explanation #3 even with various teacher supports. Some students included separate, compartmentalized claims. Other students ignored the new evidence, even those who set a context for the additional evidence. Some students attempted to generate one claim, yet struggled to develop a claim that incorporated the new evidence. Results are graphed in Chapter 4, Figure 4.6.

<u>Explanation #4</u>: A fourth piece of evidence – dissolved oxygen - needed to be incorporated into the explanation. Student groups mainly found positive results, although some groups' results were mixed. Some students effectively incorporated teacher feedback received from Explanation #3, along with the fourth piece of evidence, to generate appropriate claims. The number of students who had problems with their claims decreased by a third. Other students did not effectively incorporate either teacher feedback or evidence from the fourth water quality measure. These

students' claims reflected a range of problems. A graph to compare students' claim scores from Explanations #3 and #4 is presented in Figure 4.8 of Chapter 4.

7.3.2 Claims - Research Question Two: What are the patterns that students' claims progress through in the various iterations of an evolving explanation?

When looking at students' claims over the four iterations of the evolving explanation, several patterns emerged. Table 4.4 from Chapter 4 summarizes these major patterns and is presented again.

Table 4.4: *Patterns of Claims in the Evolving Explanation*

Pattern	Description
Direct – straight and narrow	Claims begin across all categories (1-5) prior to the introduction of the explanation framework followed by synthesized, complete claims (5) for Explanations #2, #3, and #4. (Carla)
Wandering – a bit off the path	No claims (1) or vague claims (3) initially followed by minor back and forth movement between partial (4) or complete (5) synthesized claims for Explanations #2 and #3. Synthesized, complete claims (5's) for Exp. #4. (Katherine)
Sawtooth – up and down then up	No claims (1), vague claims (3) or synthesized, complete claims (5) prior to introduction of the explanation framework followed by partial (4) or complete (5) synthesized claim for Explanation #2. Problem claims (2) in Explanation #3, followed by synthesized complete claims (5) for all but one with synthesized partial claim (4) in Explanation #4. (Mary)
Lost than Found	Problem claims (2) for Explanations #1, #2, and #3. Synthesized complete (5) or synthesized partial claims (4) for Explanation #4. (Erica)
Lost, found, then lost	Problems claims (2) prior to the introduction of the framework followed by complete (5) or partially (4) synthesized claim for Explanation #2. Problem claims (2) in Explanations #3 and #4. (John)
Going well then fell apart	Initial claims complete or partial synthesis (4 or 5), followed by complete synthesized claims (5) for Explanations #2 and #3. Problem with claims (2) in Explanation #4. One student's pattern: 5, 5, 2, and 2. (Paul and Mike)
Lost from beginning to end	All four iterations of the explanation with categories ranging from 1-3. None able to make either a partially or completely synthesized claims throughout. (Ellen)

Although their claims prior to the explanation framework spanned the entire gamut of possible claims, 13 students developed complete, synthesized claims for Explanations #2, #3, and #4. Their pattern overall was *Direct* (Straight and Narrow), as seen in the far left column of Table 4.4. The numbers in the parenthesis in the table reflect the categories of claims articulated in Table 4.2: 1. no claim, 2. attempted claim with problems. 3. vague claim, 4. synthesized, partial claim, and 5. synthesized, complete claim. In addition to the 13 students

with *Direct* patterns, 13 other students developed complete, synthesized claims for the final explanation (Ex4) but their patterns were not direct rather, instead were varied; they were *Wandering* (a bit off the path), *Sawtooth* (up and down then up), or *Lost then Found* throughout the evolving explanation. In the end, however, each of the students was successful. Two additional students had claims that were *Lost* for the first three iterations but who finally developed synthesized claims that were partially complete (*Lost and then found*). Students' names are found in the parentheses in the table. These were examples of students who fit into those categories. Discussion of these students and patterns may be found in Chapter 4, Section 4.6.2.

Thirty students, in total, were not successful in making appropriate claims in the evolving explanation and followed one of three patterns: *Lost, found, then lost, Going well then fall apart, or Lost from beginning to end.* Of these 30 students, 24 made accurate claims when evidence was consistent (pH and temperature both positive) in Explanation #2. This result leads to a question about what challenges students to adjust claims in light of new evidence.

7.3.3 Claims - Research Question Three: What are the challenges that students face in developing one claim over time?

Although more research is needed, there appear to be several challenges for students to generate claims based on evidence that is gathered over time. Findings from the research suggest several challenges and these are summarized below.

1. Adjusting one’s claim after obtaining new evidence that is inconsistent with a student’s present claim presents a challenge for many students. This is when a complex phenomenon is under investigation and a previous claim was fully supported by the available evidence and then is no longer supported by new available evidence.
2. Synthesizing several pieces of evidence, some of which is inconsistent, into one claim was very challenging for these grade 7 students. Working to incorporate new evidence into an existing claim can be “messy”. These grade 7 students appeared to wrestle with incorporating new ideas. In the same iteration, students moved back and forth between claims, sometimes making contradictions, often times showing signs of confusion. They struggled to synthesize new evidence into an appropriate, overall claim.
3. Some students thought separately about each water quality test and generated multiple sub-claims. Sometimes these sub-claims were physically separate from one another in the explanation. It appeared that for this task, these students were only able to focus on one piece of evidence at a time.
4. Some students exhibit an inability to attend to new information; they ignored new evidence and set no context for a new water quality test, even though they discussed the water quality test results at a later time within their explanation.

Table 4.3 in Chapter 4, and also presented here portrays some of the challenges that students faced.

7.4 Science Ideas: Research Questions and Summary of Findings

Reasoning was defined as using science ideas to discuss evidence and was explored separately in Chapters 5 and 6. Chapter 5 explored Research Questions Four and Five that looked solely at science ideas to investigate the development of students’ understanding of science ideas across time.

2a. Ignore describes context	2b. Ignore no context	2c. Separate claims	2d. Ignore & separate claims	2e. "Messy"
1. Student sets context for all water quality tests 2. Ignores the new evidence in his/her claim 3. Claim not adjusted	1. Student does not include new water quality test in context 2. Ignores new evidence in claim 3. Claim not adjusted	1. Student makes separate claims as new evidence emerges 2. little/no synthesis 3.Compartmentalize	1. Student both ignores new evidence and make separate claims 2. Little/no synthesis 3.Compartmentalize	1. Student attempts to synthesize new evidence 2. Struggles to adjust claim 3. Claim confused/messy 4. No overall claim (for some)

Table 4.3: *Attempted Claims – Category 2: Claims with Problems Elaborated*

7.4.1 Science Ideas - Research Question Four: As students engage in writing an evolving explanation, how does their understanding of science ideas develop across time?

The findings showed that when initially writing about phenomena, students included few, if any, science ideas. Looking at how students' science ideas develop across the various iterations of the explanation, results indicated a significant effect. As seen in Tables 5.1 and 5.2 of Chapter 5, separate statistically significant results about science ideas were obtained across the four iterations for the pH measure and for the temperature measure, respectively. The conductivity measure for Explanations #3 and #4, the only iterations that included this measure, also indicated a significant effect (See Table 5.3 in Chapter 5). Students did not write a second iteration for the dissolved oxygen measure because it was only included in the final iteration. In summary, the iterative approach of the evolving explanation assisted students to progressively build understanding of science ideas over time. Their use of science ideas and relationship between those science ideas increased significantly with each iteration of the explanation.

7.4.2 Science Ideas - Research Question Five: How does the practice of analyzing data/evidence and writing the first two iterations of an evolving explanation allow students to transfer their learning to new situations?

Once students had initial experiences and then included new evidence into their explanation that needed to be discussed using new science ideas, they incorporated science ideas and made connections between those science, seeing relationships, much more than in their earlier explanations. The first time students include conductivity (the 3rd water quality measure included for the first time in Explanation #3) and dissolved oxygen ideas (the 4th water quality measure included for the first time in Explanation #4) into their explanations, the number of science ideas they included were significantly higher than the number of science ideas included the first time students incorporated pH and temperature ideas (the first two water quality measures included in Explanation #2). These results are presented in Table 5.4 in Chapter 5, and suggest that as students gained more experience, they were able to transfer their learning to new situations, both related to the practice of constructing explanations and how to think more deeply about science ideas by making connections between them.

7.5 Reasoning - Connection Science Ideas with Evidence: Research Questions and Summary of Findings

Chapter 6 explored Research Questions Six-Nine related to students' progress towards making connections between science ideas and evidence, or reasoning. As well, the chapter explored the interplay between understanding of science ideas with connections that students made to evidence, and also explored if a relationship existed between these and the success of students to generate accurate claims.

7.5.1 Reasoning: Connecting Science Ideas with Evidence - Research Question Six: How do students connect science ideas with evidence and are students able to make more connections to evidence over time?

Initially, most students made no connections between science ideas and evidence - meaning that they did not include reasoning in Explanation #1. Across the four iterations a statistically significant difference occurred for all water quality measures. I conjecture that the statistically significant results indicate that the use of synergistic scaffolds (Bransford et al., 2000; McNeill & Krajcik, 2009; Quintana, et al., 2004; Tabak, 2004) along with the iterative nature (Bransford, 2000; Fortus & Krajcik, 2011; NRC, 2010; 2013; Nelson & Hammerman, 1996) of an evolving explanation worked together to support students' thinking. As a result, students were able to make use of their science ideas by making more and more connections over time.

7.5.2 Reasoning: Connecting Science Ideas with Evidence - Research Question Seven: Does the process of writing the first two iterations provide students with experience to make more connections of science ideas with evidence when writing about new evidence: Is there transfer?

When looking to see if students made more science connections to evidence when writing about new evidence after they had some experience, the results indicated a statistically significant difference (See Chapter 6, Table 6.1). Students made more science connections to evidence when writing about new evidence related to conductivity and dissolved oxygen, in Explanations #3 and #4 respectively, after they had some experience, than they did when writing about pH and temperature evidence, in Explanation #2. The results of this study provide evidence that earlier academic learning can support students in future learning.

7.5.3 Reasoning: Connecting Science Ideas with Evidence - Research Question Eight: How do the levels of understanding that students possess about science ideas relate to the connections to evidence students make over time?

Results indicate that as students develop understanding of more of the relationships between science ideas for a particular water quality measure, they are able to make more connections to evidence. Two separate analyses were used to investigate this eighth research question. First, looking separately at each water quality measure across all four iterations of the explanation using multiple regression analysis all variables for each water quality measure showed to be statistically significant. These findings suggest that connections are dependent on the level of understanding of science ideas. Second, an additional analysis was conducted to look at each explanation that included all of the water quality measures for that explanation. The earlier results were confirmed, suggesting that connections were dependent on understanding of science ideas. Findings are illustrated in Chapter 6, Tables 6.3, 6.4, and 6.5.

7.5.4 Reasoning: Connecting Science Ideas with Evidence - Research Question Nine: What is the impact of students' understanding of science ideas and/or connections on their ability to adjust claims when faced with new evidence?

Research question nine sought to gain insight related to what students base their claims on. Results indicated no statistically significant differences when trying to determine if connections to evidence or science ideas was predictive of claims that students generated. The overall data, I believe, suggests that all students made great strides towards developing understanding of science ideas and in their reasoning, their connections of science ideas to evidence. The challenge for about 50% of the students, however, was to align their claim when faced with new, anomalous data (Chinn & Brewer, 1998, 1993) that contradicted their previous claim that at the time was supported by the evidence. Results may be found in Chapter 6, Tables 6.6 and 6.7.

7.6 Toward an Integrated Understanding using all Four Iterations of the Evolving Explanation

If students have integrated understanding they should be able to generate a claim that is supported by evidence and use science ideas to justify why the evidence supports the claim (Berland, & Reiser, 2009; McNeill & Krajcik 2011; NRC 2007; 2012). Thus far I have teased apart various components of scientific explanations to deeply explore the separate components. In this section, I tie all of the separate pieces together to discuss the results as a whole. I expand on findings from the research questions in this thesis to more deeply explore how to assist students towards developing integrated understanding.

I look at integrated understanding of experts, helping students towards development of integrated understanding, and the use of an evolving explanation to assist students. Next, I look at the development of integrated understanding of students in this study across the four iterations of their evolving explanation. Included in this section is discussion of scaffolds, transfer, feedback and practice.

7.6.1 What does Integrated Understanding Look Like – Experts?

Experts have well-developed knowledge structures, or integrated understanding, with knowledge that is organized around core concepts or 'big ideas' that guide their thinking (Chi, Feltovich, & Glaser, 1981; Hmelo-Silver & Pfeffer, 2004; NRC 2000; 2007). This highly organized knowledge allows experts to think about and then explain phenomena and solve problems, allowing them to be ready to learn new ideas. In Figure 7.1, I present a representation that could illustrate what an expert's integrated understanding looks like and how it could help him/her explain a phenomenon.

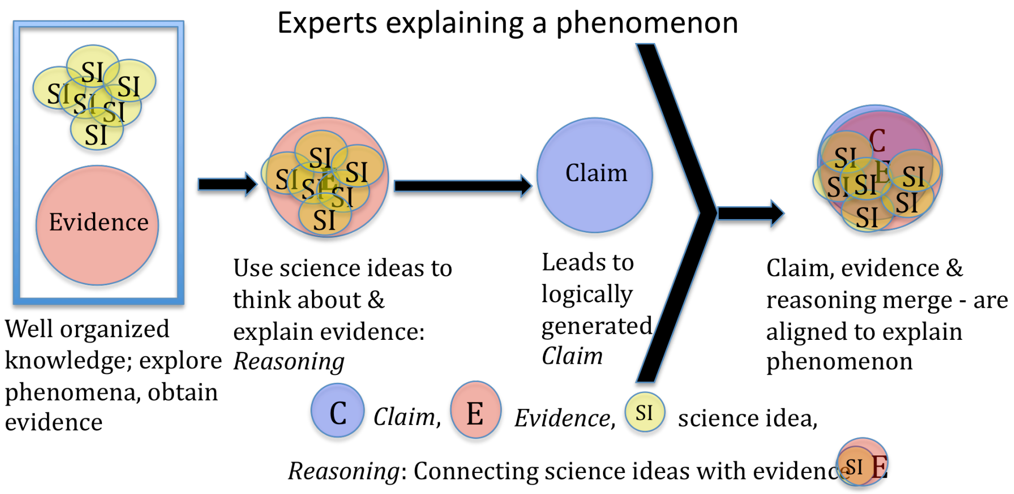


Figure 7.1: Experts Explaining a Phenomenon

The far left portion of Figure 7.1 shows that experts have science ideas that are connected. These ideas are represented by circles labeled SI (science ideas) that overlap; they understand relationships between science ideas that lead to well-developed knowledge structures (Chi et al., 1981; Hmelo-Silver & Pfeffer 2004; Linn et al., 2008). This well-organized knowledge allows them to apply their understandings to new situations. When they obtain evidence from exploring a phenomenon, experts use their science knowledge to think about and to explain that phenomenon. This includes generating a logical claim. In the end, their claim, evidence, and reasoning (connecting science ideas with evidence) merge; they align so that experts are able to explain phenomenon with high levels of sophistication.

7.6.2 Helping Students towards Integrated Understanding

The purpose of this study was to explore how to assist students towards developing an integrated understanding. Integrated understanding will assist students towards improved scientific literacy. Becoming scientifically literate in order to understand and explain the natural world, solve pressing local and global problems, and make decisions is stressed in The New Framework for K-12 Science Education in the United States (2012), the Organization for Economic Co-operation and Development (OEDC, 2004), as well as in other documents (Choi, 2011; NRC, 2007). Experts are scientifically literate and students need to experience instruction that promotes their thinking towards scientific literacy.

7.6.3 Evolving Explanation and Development of Integrated Understanding

Students in the science classes studied in this thesis explored a complex phenomenon within a project-based (Krajcik & Czerniak, 2014, Krajcik & Blumenfeld, 2006) science curriculum based on 3-dimensional learning, the pedagogical approach envisioned by the New Framework for K-12 Science Education (2012). The three dimensions include disciplinary core ideas, cross-cutting concepts, and practices. Learning experiences should provide students with experiences that blend these three components. In research presented in this thesis, the practice of constructing *scientific explanations*, the crosscutting concept of *cause and effect*, and disciplinary core ideas that blended science ideas from *Earth and Human Activity*, and *Ecosystems: Interactions, Energy, and Dynamics* related to water quality were the focus. Figure 3.1, in Chapter 3, summarizes the practices, cross-cutting concepts, and disciplinary core ideas that were part of the curriculum that was explored in this thesis. The curriculum also worked towards several performance expectations (NGSS, 2013; also see Appendix A). Furthermore, through this curriculum students experienced nature of science ideas (NGSS, Appendix H, 2013), specifically that when investigating phenomena new evidence may emerge that necessitates having an open mind to the possibility of revising one's current thinking. Over time, students moved from less sophisticated understanding towards more sophisticated understanding as they worked towards developing knowledge structures or an integrated understanding.

As part of their experience, these students constructed one explanation, over a period of time, termed an evolving explanation, as they collected water quality data over a six-week period. The explanation evolved through four iterations as students collected additional evidence. Students needed to incorporate this new evidence into their existing explanation. The new evidence included new science ideas. For each piece of evidence, students focused on the causes and consequences related to the particular water quality measure. Students also received teacher support including teacher feedback. The purpose of the feedback was to assist students to clarify and expand science ideas, to build understanding of relationships between ideas, expand their thinking, rethink if needed, and to consider alternatives.

The goal of instruction was to assist students to develop integrated understanding; as students developed their explanation over time, not only would they include more science ideas, but those science ideas would become more connected, allowing students to tell a richer, more sophisticated "story" of the health of a stream for freshwater organisms that was the explanation of the phenomena.

If successful, not only would students be able to use their understanding to explain the phenomenon but they would also be prepared for future learning. As Chi, Feltovich, & Glaser (1981), and Hmelo-Silver and Pfeffer (2004) point out and as stated as a goal of science education in National Research Council documents from the United States like *Taking Science to School* (NRC 2007) and *How People Learn: Brain, Mind, Experience, and School* (NRC, 2000), experts have well-organized knowledge. This is because they understand relationships betweens science ideas and can apply their understandings in various contexts. When students realize science ideas are connected and make deliberate efforts to apply their understanding of science ideas in order to explain phenomena, Kali, Linn, and Roseman (2008) suggest that students have integrated understanding. This is because, as Fortus and Krajcik (2011) point out, students' ideas are connected to each other and students are both aware of and able to use relationships to explain phenomena and solve problems. But these sophisticated understandings cannot develop in a short amount of time and students need to revisit ideas in a progressively iterative manner (Fortus & Krajcik 2011; NRC 2000; 2010; 2013; Nelson & Hammerman, 1996).

Constructing an evolving explanation allows students to revisit science ideas and to build on those understandings. Additionally, the process simultaneously assists students in constructing explanations, an important scientific practice that is seen multiple times throughout the New Framework (2012) and other documents including, *Ready, Set, Science,* (National Research Council, NRC, 2008) *Taking Science to School*, (NRC 2007), *How People Learn: Brain, Mind, Experience, and*

School (NRC, 2000), the *National Science Education Standards* (NRC 1996), the AAAS Project 2061 *Benchmarks* (1993), and *Science for All Americans* (1989).

7.6.4 Results: Integrated Understanding?

So did an evolving explanation within a 3-dimensional learning environment assist students toward developing integrated understanding? Keeping in mind the representation of how experts explain phenomenon illustrated in Figure 7.1, in the following section I look at the study's results through the various iterations of the evolving explanation. Discussion will focus on major findings that describe most students.

For each explanation, I will provide representations that illustrate the general types of explanations students constructed. I will use the same components that were included in Figure 7.1: Experts Explaining a Phenomenon. A key at the bottom of each figure includes science ideas that either overlap to represent that students' explanations showed understanding of relationships between the ideas or that do not overlap showing disconnected ideas. The key also includes missing science ideas, evidence, and claims. When science ideas and evidence overlap, this represents reasoning – that students connected science ideas to evidence. When all components overlap, this represents integrated understanding where students were able to generate accurate claims from reasoning thus applying their understanding. This would be the ultimate representation of integrated understanding of student experts. It is what is represented in 7.1, Experts Explaining a Phenomenon.

Explanation #1: Two pieces of evidence and BEFORE the introduction of the explanation framework

In two separate data collection episodes, students collected two pieces of data -- pH and temperature - that included both qualitative and quantitative data. Results from both water quality measures were positive for fresh water organisms with results falling into the "excellent" and/or "good" ranges based on National Water Quality Standards for freshwater (Stapp & Mitchell 1995). Before being introduced to the explanation framework students were asked to write what they thought a scientist would write to answer the question, “How healthy is the stream for freshwater organisms based on what we know?” This is identified in the study as Explanation #1.

Figure 7.2 illustrates four general types of explanations that students generated. This initial, Explanation #1, was written prior to being introduced to the explanation framework. Some students made vague claims and presented evidence (Ex1a). Some students made a claim and presented evidence to support that claim, merging claim and evidence (Ex1b). Some students presented no evidence (Ex1c) and other students presented no claim (Ex1d). A few students failed to include a claim, evidence, or science ideas (not represented in Fig. 1). In other words, students’ initial explanations exhibited a wide range. There was one consistent feature among the various initial explanations though; the majority of students included no science ideas (represented by empty circles as missing science ideas) to show why the evidence supported the claim.

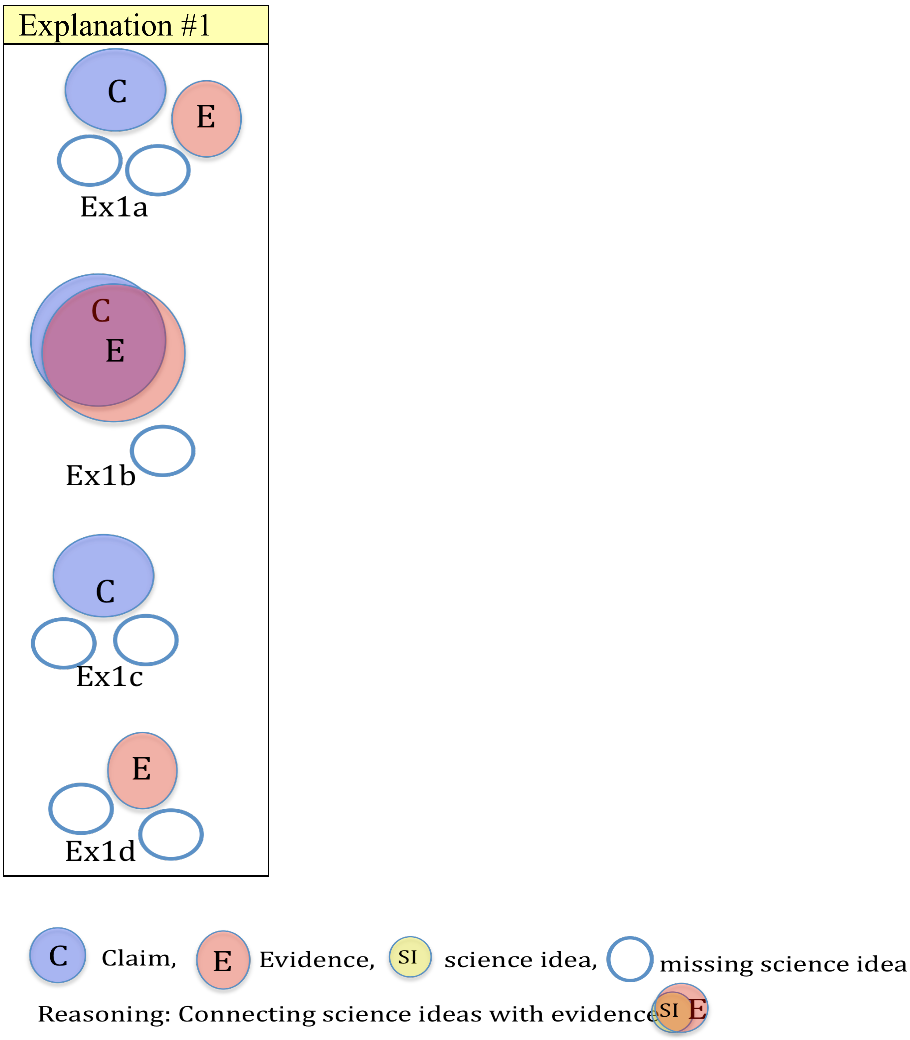


Figure 7.2: Explanation #1 – Two Pieces of Evidence BEFORE the Introduction of the Explanation Framework

All of these results made sense, as students were unfamiliar with the explanation framework. These initial explanations, however, served as an important baseline to track students' development towards integrated understanding.

Explanation #2: Two pieces of evidence and AFTER the introduction of the explanation framework

The teacher introduced students to the explanation framework, provided students with a scaffolded guide sheet, and students completed the guide sheet with partners and then developed Explanation #2. Eighty percent of students in this iteration of the evolving explanation, now made an accurate claim supported by the evidence, that is 47 students made accurate claims in Explanation #2 compared to only five students in Explanation #1 who made accurate claims. Three students made vague claims, seven attempted claims but had problems, and one student made no claim.

The two pieces of evidence, pH and temperature were consistent; both were positive for the water quality of the stream and thus, for organisms in the stream. The four different representations of students' initial explanations, prior to knowledge of the explanation framework, shown in Figure 7.2, now converge into one type of explanation, for the second iteration found in Figure 7.3. Claim and evidence circles, therefore, overlap in Figure 7.3; they are integrated and align. Claims for Explanation #2 were logically generated from the evidence. As such, with two pieces of consistent evidence, the claim was easily accessible to students in this study. This is consistent with research findings of Berland and Reiser (2009), McNeill and Krajcik (2007 & 2011), and McNeill and colleagues (2006)

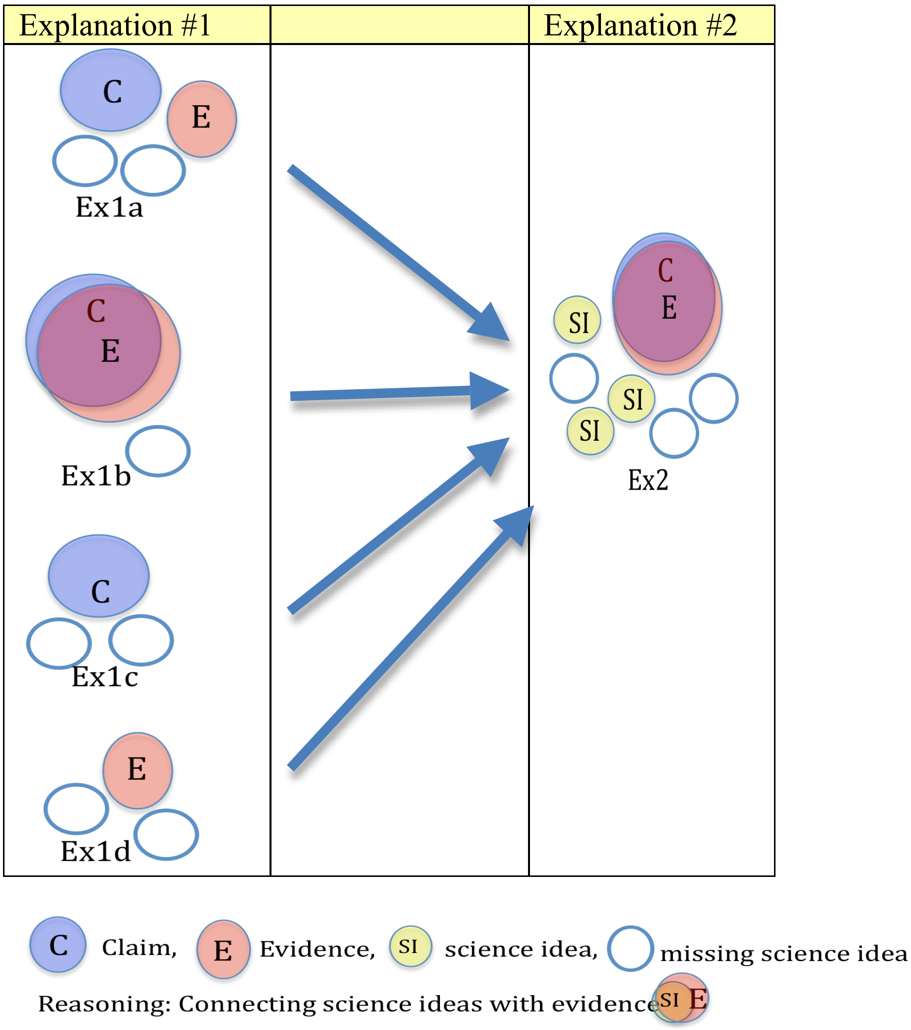


Figure 7.3: Explanation #2 – Two Pieces of Evidence After the Introduction of the Explanation Framework

Notice as well in Figure 7.3, that students' second iteration of the explanation now also included some science ideas. Students presented some science ideas but did not show any relationships between those ideas. Therefore, the science ideas that are part of Explanation #2 represent pieces of disconnected facts rather than being part of integrated understanding (Kali et al, 2008) where knowledge is organized around core ideas like those of experts (Chi, Feltovich, & Glaser, 1981; Hmelo-Silver & Pfeffer, 2004; Linn et al., 2008; NRC, 2000; 2007). Science ideas were also unconnected to evidence; students did not use them to explain how the evidence supported the claim. Parten (1932) describes parallel play where children play side by side play but never interact with each other. This situation is similar; students presented some science ideas and also presented some evidence but never connected them to each other. Research has shown that using science ideas to explain evidence, termed reasoning, is challenging for students (Berland & Reiser, 2009; McNeill & Krajcik, 2006) so the results here are consistent with existing evidence.

Explanation #3: Three pieces of evidence - New Contradictory Evidence

After constructing Explanation #2, students received written teacher feedback. The purpose of the feedback was to assist them to make connections, expand their thinking, rethink if needed, and to consider alternatives. Additionally, students collected a third piece of evidence, conductivity data. Results from this water quality measure were poor, with too many dissolved solids. Students were now expected to incorporate this new evidence into the explanation. Explanation #3 included revisions of pH and temperature ideas, based on teacher feedback, and also inclusion of the new evidence and science ideas related to conductivity. Figure 7.4 illustrates students' development from Explanation #2 to Explanation #3.

Comparing science ideas represented in Figure 7.4 to science ideas in Figure 7.3, two developments in the third iteration of the explanation were evident. First, there were more science ideas and fewer blank circles that represented missing science ideas. Second, those science ideas overlap. This overlap illustrates that students were seeing more and more relationships between those ideas, thus working towards developing a deeper understanding of science ideas (see Chapter 5, section 5.7.1 for a more thorough discussion).

As Krajcik and Shin (2013) point out, and what is also expressed in the National Research Council documents like *How People Learn: Brain, Mind and…* (Bransford et al., 2000) learning complex ideas takes time. These understandings can be of science ideas and of the practices of "doing" science (Bransford et al., 2001; NRC 2014). The iterative nature of the evolving explanation, and social nature of constructing understanding (Vygotsky 1986) provided students with opportunities and time to revisit "old" ideas that allowed them to progressively build an understanding of more relationships between ideas.

Time, in and of itself, however, is not enough. As with McNeill and Krajcik's work (2008), which showed that teachers' instructional practices assisted students to construct explanations, results of this study indicated that the teacher played a key role in supporting students. These strategies included teacher feedback and a collaborate process where partners worked together to complete teacher prepared, scaffolded guide sheets. Providing students with these synergistic scaffolds and time to think about and incorporate that feedback assisted them to see more relationships. As Quintana and colleagues (2004), Tabak, (2004), and McNeill and Krajcik (2009) suggest, multiple forms of support worked together to assist students to build stronger understanding. Without these supports students may, as Reiser (2004) stated, overlook or superficially address important aspects of a task.

Building stronger understanding of pH and temperature ideas, however, was only part of Explanation #3. New science ideas related to conductivity were also incorporated into this explanation. Students were not revisiting these science ideas; they were engaging with them for the first time. In this iteration of the explanation, Explanation #3, students included many more science ideas related to conductivity than they did for pH or temperature in Explanation #2. This was the first time that students wrote about these ideas after they were introduced to the explanation framework. Consequently, a powerful finding of this study suggests that these students were able to transfer their learning. They were, as Bransford and Schwartz (2001) propose, prepared for future learning because they were able to extend what they had learned about constructing explanations using science ideas to the new context of conductivity data. These students were able to extend what was learned in one context to a new context. Not only did these grade 7 students present more science ideas, they were able to show more relationships between the ideas then they were in Explanation #2 for pH and temperature ideas (See Chapter 5, section 5.7.2 for more in-depth discussion). They were able to apply what they previously learned as well as learn associated ideas more quickly (NRC, 2001). Results for Explanation #3 indicated that most students were building stronger understanding of ideas, for pH, temperature, and conductivity.

In addition to including more science ideas in their explanations and seeing relationships between those ideas, these results indicate that most students connected more and more of those ideas to their evidence. These students were integrating science ideas with evidence suggesting that their ability to *reason,* the most challenging aspect of explanations (Berland & Reiser, 2009; Gotwals & Songer, 2006; NRC 2007; McNeill & Krajcik, 2006) was improving (see Chapter 6 for more in-depth discussion, Section 6.8).

However, results suggest that not all students were able to apply those understandings to generate appropriate claims. The percent of students generating appropriate claims decreased from 80% in Explanation #2 to 40% in Explanation #3 even with various teacher supports. Looking at Figure 7.4, three patterns emerged to describe students' progression from Explanation #2 to Explanation #3. To review, pH and temperature evidence was identified as "excellent" and/or "good" water quality (Stapp & Mitchell, 1995) suggesting the stream to be healthy for freshwater organisms. Conductivity evidence was identified as "poor" water quality, suggesting problems for freshwater organisms. This meant that all students needed to rethink their initial claims and generate a new claim based on all of the available evidence.

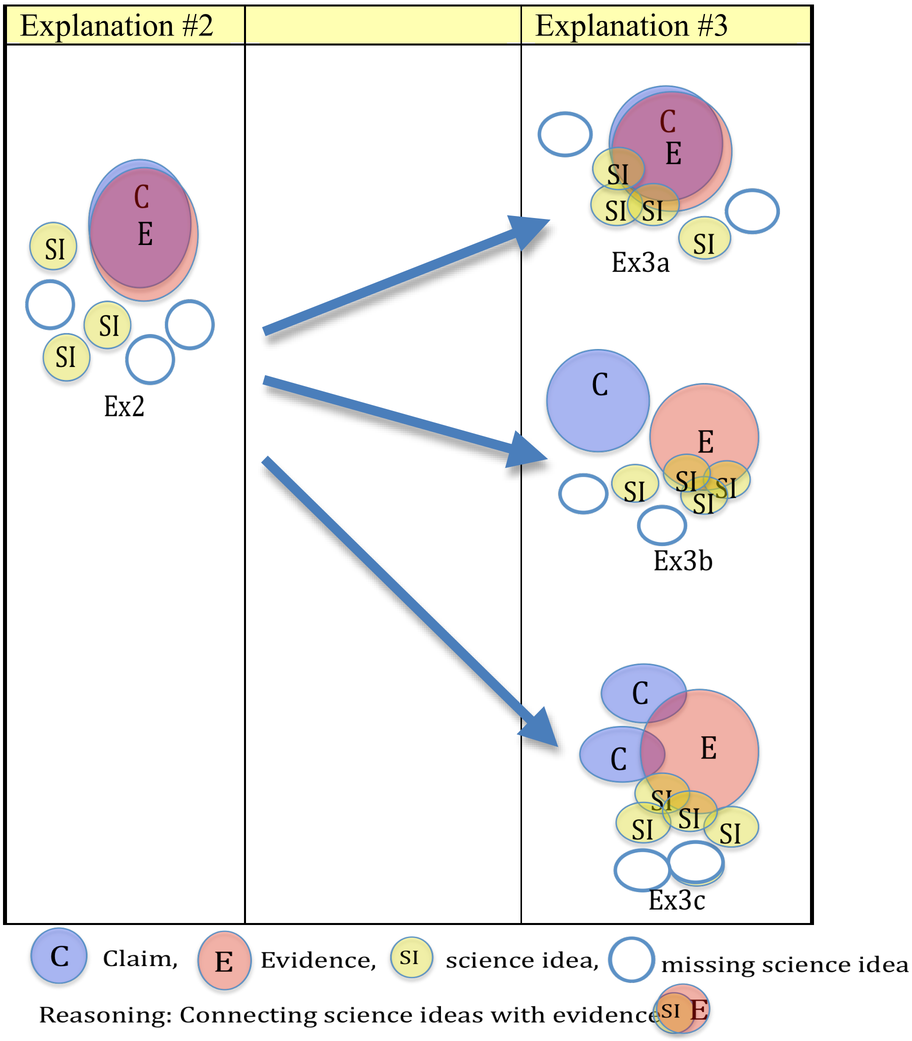


Figure 7.4: Explanation #3 – New, Contradictory Evidence (3 pieces of evidence).

For the first pattern that emerged, some students were able to incorporate the new, contradictory evidence into their claims by appropriately adjusting them. These students are represented in Figure 7.4 as Ex3a. Their claim and evidence align. These students were also generating more science ideas, seeing more relationships between those ideas (represented by science ideas overlapping) and they exhibited some reasoning, making connections between those science ideas and evidence (represented with some overlapping of science ideas and evidence in Figure 7.4). With additional teacher feedback, as is discussed in the next section for Explanation #4, many of these students fully integrated science ideas with evidence, thus developing strong reasoning.

For the second pattern, just like students with explanations represented in Ex3a, students whose explanations are represented as Ex3b in Figure 7.4, also included more science ideas and relationships between those science ideas and they also exhibited some reasoning, making connections between those science ideas and evidence. However, these students did not adjust their claims. The “claim” portion of the *claim, evidence, and reasoning* framework is viewed as the most accessible part of explanations (Berland, & Reiser, 2009; McNeill & Krajcik, 2007: 2011; McNeill et al., 2006), most likely because it is often straightforward. In this more complex explanation, however, the claim is more challenging. Students did not, as Duschl (2007) and Sampson and Clark (2006) suggest, examine their claim to see if it took into account all of the available evidence. Perhaps as Chinn and Brewer found with students (1993, 1998) and as Kuhn (1996) found with experts, that they ignored or otherwise discounted evidence that was inconsistent with their current thinking. Did they have trouble “letting go” of ideas as Brandsford and Schwartz (2001, p.21) refer to as negative transfer? Perhaps these are the reasons that contributed to these students’ challenges with adjusting claims.

Choi and colleagues (2011) stress metacognition and self-direction as a component of scientific literacy suggesting that students need to have regular opportunities for reflection. Perhaps students did not intentionally disregard evidence but instead failed to attend to the task of even thinking about and considering this new evidence relative to their claims. Metacognition, or lack there of, may have contributed. Reflection may not be a regular part of many students’ experiences in the United States. Providing students with opportunities to reflect upon their claims through classroom discourse, as Reiser and colleagues (2012) and Berland and colleagues (in press) suggest, could be the support that students need to engage in the reflection process that assists them to “let go” and build new claims together.

The teacher in this study attempted to support students to reflect on their current claims through guide sheets that included the prompt, “*Do you need to change your current claim?”* This guide sheet was preceded by a classroom discussion where she verbally prompted students to think about their current claims in light of new evidence. Reflecting on the claim, however, was one of multiple tasks students engaged in with student partners as they collaboratively completed the guide sheet. Breaking this larger task into smaller tasks that made “thinking about one’s claim” as a separate task may have helped to focus students’ attention solely on the claim. More research is needed to investigate this idea. Another possibility of why students did not attend to the task of rethinking their claims is that they are unaccustomed to these types of experiences. Revising one’s work or building on previous work is not a common experience in science classes like it may be in students’ English classes. The common core, for example, includes several standards (e.g,.W.7.5 and W.7.10) related to revision (http://www.corestandards.org/ELA-Literacy/W/7/).

A third pattern emerged in Explanation #3, represented in Ex3c. As with the other two patterns, the majority of students included more science ideas and relationships between those science ideas and they also exhibited some reasoning, making connections between those science ideas and evidence. But, instead of adjusting their claims to incorporate all three pieces of evidence into one, new claim, and instead of ignoring or not recognizing that the claim needed attention, this group of students presented two claims; the initial claim, which was positive based on pH and temperature evidence, and a second claim for conductivity, which was poor. Some students’ claims were in the same paragraph. Some students’ claims were in separate sections. But regardless of where they physically were located in the explanation the claims contradicted each other; the stream cannot be healthy and unhealthy for freshwater organisms simultaneously. Figure 7.4, Ex3c illustrates separate claims connected to evidence. Claims based on evidence obtained from this complex phenomenon were not “logically bound by the evidence” as were claims studied by Berland, and Reiser, (2009, p. 22). I propose that developing a claim that is not clear-cut is a very challenging undertaking and that these grade 7 students do not regularly have these types of experiences.

Explanation #4: Four pieces of evidence - New Evidence

After constructing Explanation #3, all students, once again, received teacher feedback. Additionally, all students collected a fourth piece of evidence -- dissolved oxygen data. Because of various environmental factors, results from this water quality measure were mixed with some student sections having plenty of oxygen to support life, others having little oxygen, and others in-between. Students were now expected to incorporate this new evidence into their explanation. Explanation #4 included revisions of pH, temperature, and conductivity ideas based on teacher feedback, and also included new evidence and science ideas related to dissolved oxygen. In addition, students received feedback about their claims (see Chapter 4 section 4.6.1D for a more thorough discussion).

Once again, students engaged in a transfer task that involved incorporating new science ideas related to dissolved oxygen into the explanation and results indicated significant gains from the first time students incorporated science concepts related to pH. And again, most students' work exhibited more and more relationships between science ideas for all of the water quality tests as well as more and more connections to evidence. These relationships are illustrated in Figure 7.5 in Ex4a, 4b, and 4c as overlapping circles of science ideas and then those science ideas overlapping with evidence. These results indicate that students' understanding was moving along a pathway from less sophisticated to more sophisticated, although there was variability between students. Looking specifically at Ex4a in Figure 7.5, relationships between science ideas are well established and those ideas are connected to evidence. These students were able to transfer their learning to extend to dissolved oxygen, incorporating the new science ideas into their explanation for the first time (Brandsford, Brown, & Cocking, 2001; Bransford & Schwartz, 2001). There is only one claim that takes into account all of the evidence (Duschl, 2007; Sampson & Clark, 2006). Figure 7.5 illustrates students' development from Explanation #3 to Explanation #4.

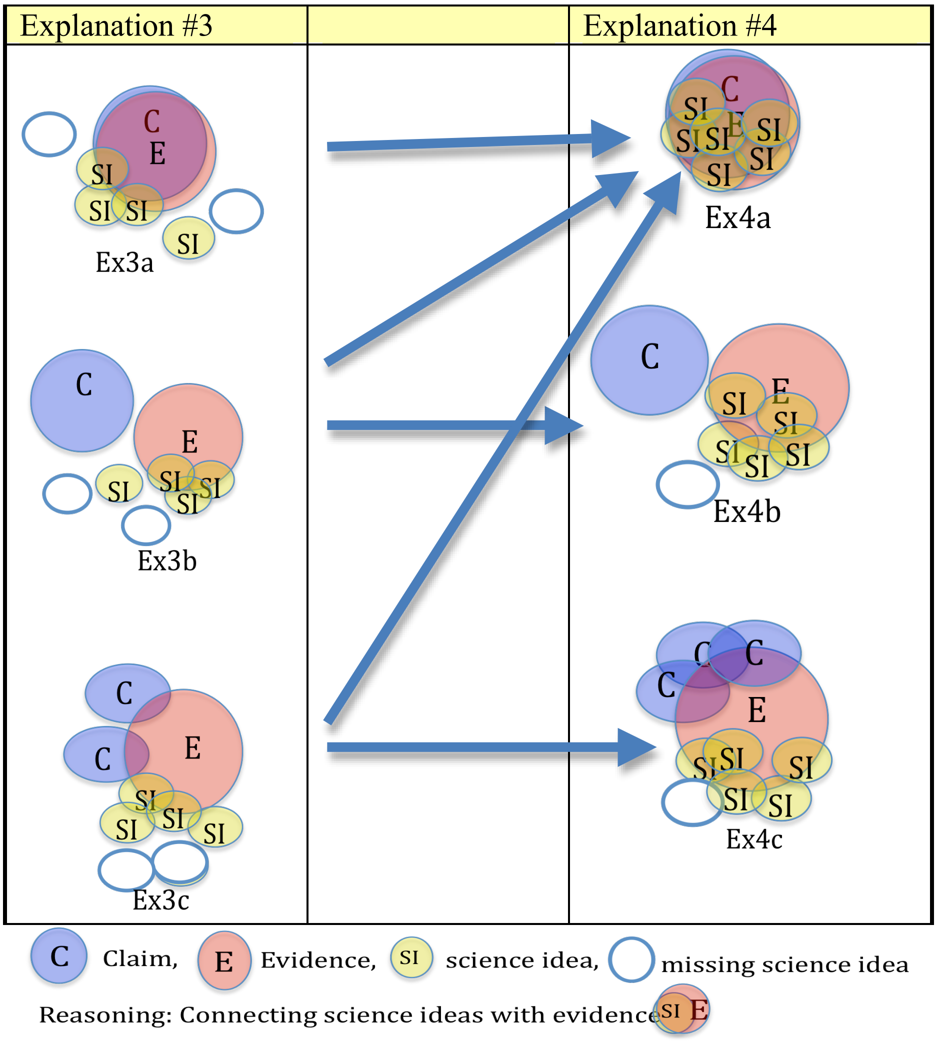


Figure 7.5: Explanation #4 – New Evidence (4 pieces of evidence)

All three components - science ideas, connections to evidence (*reasoning*), and claim - align and are merged in Figure 7.5. This representation matches Figure 7.1, *Experts Explaining a Phenomenon*. Like experts, I would argue, these student experts displayed well-developed knowledge structures, or integrated understanding around ideas related to water quality and human impact on water quality that guide their thinking (Chi, Feltovich, & Glaser, 1981; Hmelo-Silver & Pfeffer, 2004; Linn et al., 2008; NRC, 2000; 2007). Their organized knowledge allowed them to think about and then explain the complex phenomenon of the health of a stream for freshwater organisms. Over the course of the evolving explanation, these students told an ever-increasing sophisticated science "story" of the health of the stream for freshwater organisms. Using scientific practices, including constructing an evolving explanation, and crosscutting concepts of cause and effect related to each water quality measure, these students applied understanding of science ideas to explain the phenomenon, thus exhibiting the results of what 3-dimentional learning can accomplish. In other words, students need to experience curricula that is at the "the intersection of practice, content, and connection" (NGSS, p. xvi). These students should then be able to develop and apply scientific knowledge to new and unique situations and to think and reason scientifically (NRC, 2012). The students in this study engaged in exactly this type of experience. Figures 3.1 and 3.2 are a summary of curriculum's 3-dimensional learning ideas from the Framework/NGSS (NRC, 2012; NGSS, 2013).

Notice also, in Figure 7.5 that students with all types of explanations from Explanation #3 (Ex3a, 3b, and 3c) had the potential to construct an explanation that evolved into one that displayed integrated understanding, not just those students who were earlier successful at adjusting their claims. Some students, whose claims in Explanation #3 did not reflect all of the available evidence, now in Explanation #4, did. These students incorporated teacher feedback from three pieces of evidence, now added a fourth piece of evidence, and then generated an appropriate claim. Additionally, some students who generated multiple claims in Explanation #3 were now able to merge those claims into one, appropriate claim.

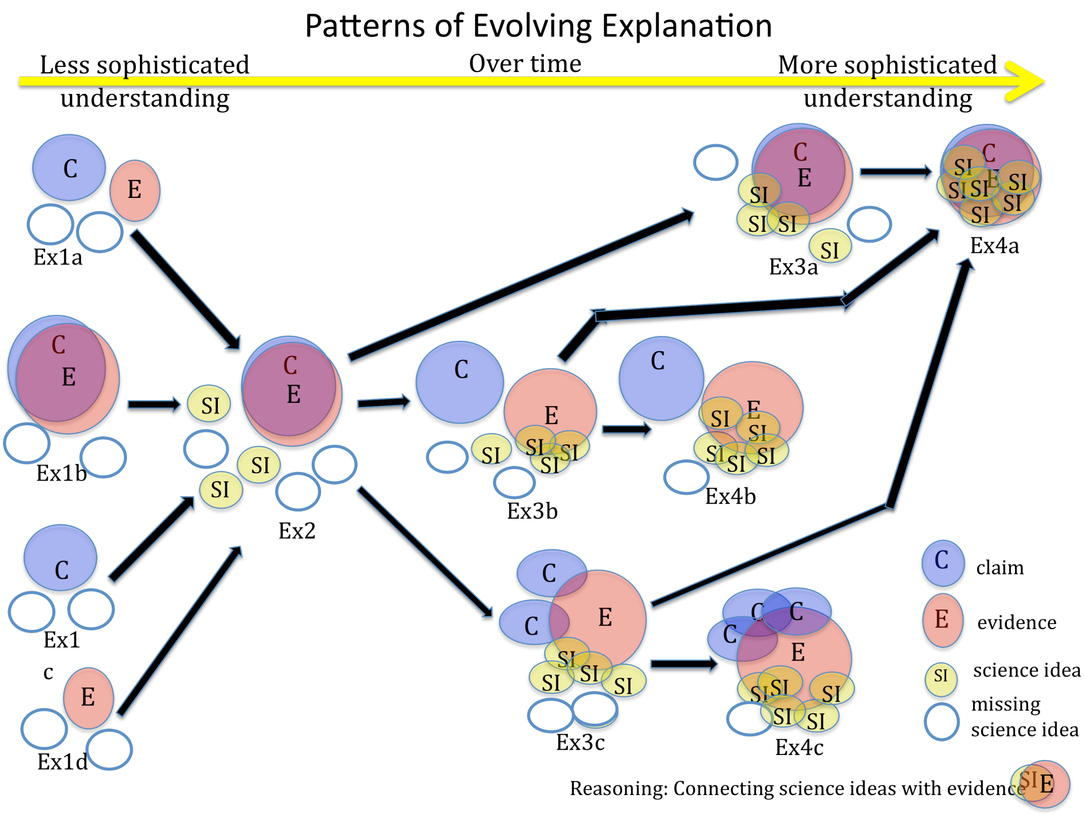
Combining the various groups of students' who exhibited integrated understanding in the final iteration of the evolving explanation where they were able to apply their understanding, represented just under 50% of the students (see Chapter 4, section 4.6.1D**)** for a more thorough discussion). It appears that teacher feedback to these students assisted them to reflect upon and rethink their claims. These results are consistent with the findings from Pellegrino, Chedowsky and Glaser, (2001), and Black (2003), showing the importance of feedback which informed students about their work that then helped to improve their learning. These authors found that practice and feedback combined was critical to the development of skill and expertise. Feedback and practice supported students in this study also towards a useful metacognitive process. Choi and colleagues (2011) proposed metacognition as a dimension for scientific literacy. Results from this study illustrate the importance of including reflection as a component of learning. Results also provide an example of the significance of providing students with multiple opportunities as a necessary condition to move from novices towards more expertise.

In the over 50% of students whose pattern did not represent integrated understanding, all students progressed towards a more sophisticated understanding. These students, however, were not successful at merging all their claims with evidence and reasoning. Explanation Ex4b, in Figure 7.5 illustrates students whose science ideas were more connected to evidence, but who still failed to adjust their claims based on all of the evidence. Students represented in Ex4c continued to struggle to integrate claims into one, appropriate claim, even though it was evident of their attempts. They did not ignore evidence (Chinn & Brewer 1998) but appeared to be reflecting on new evidence. The task appeared too cognitively challenging. What was once an appropriate claim, logically generated from evidence (Duschl, 2007; Sampson & Clark, 2006; Berland & Reiser, 2009) no longer was supported based on new evidence.

7.6.5 Summary of Results: Integrated Understanding

Students in this study constructed an evolving explanation; four versions of an explanation that became progressively more complex as students collected more and more data from a local stream. Students made revisions based on teacher feedback, added new evidence and science ideas to discuss and reason about the evidence to explain a complex phenomenon, and generated a claim in each iteration based on all the available evidence. That claim, once fully supported by the evidence, needed to be adjusted as new evidence emerged. The goal was to assist students to develop an integrated understanding that meant they had knowledge structures that allowed them to use their knowledge (Bransford, Brown, & Cocking, 2000; Fortus & Krajcik, 2011; Hmelo-Silver, & Pfeffer, 2004; Roseman, et al., 2008), in the case of these students to explain the health of a stream to support freshwater organisms. Figure 7.6 is a summation of Figures 7.2, 7.3, 7.4, and 7.5 that illustrates student development over the course of all four iterations of the evolving explanation.

Overall results indicate that all students' understanding of science ideas as seen through the increase in both the number of science ideas as well as in the relationships between those ideas developed from iteration to iteration across all four. All students also increasingly connected science ideas to their evidence, called reasoning, that research shows is the most challenging part for students (Berland & Reiser, 2009; Gotwals & Songer, 2006; NRC 2007; McNeill & Krajcik, 2006). This result illustrates that students' understanding moved from less sophisticated to more sophisticated.



Explanation#1 Explanation #2 Explanation#3 Explanation#4

Figure 7.6: Towards an Integrated Understanding: Progression of All Four Iterations of the Evolving Explanation

The component of explanations that research indicates is often the most accessible to students is the claim (Berland, & Reiser, 2009; McNeill & Krajcik 2007; 2011; McNeill et al., 2006). When claims have been a challenge for students it stems from studies such as Sadler's and colleagues (2004) related to socioscientfic issues where students are presented with conflicting information from different sources. In this study, however, the claim became particularly challenging as students needed to negotiate several pieces of evidence, some of which was positive for freshwater organisms and some which was not, and then develop a claim that was generated from all of the evidence (Duschl, 2007; Sampson & Clark, 2006), by revising and/or reinterpreting their findings based on the new evidence (Nature of Science Matrix, NGSS Appendix G, 2013) each time new data were obtained and analyzed.

Results indicate that about 50% of students were able to align their claims with evidence and reasoning along the pattern illustrated in Ex4a in Figure 7.6. These students were considered to have developed integrated understanding (Fortus & Krajcik, 2011; Hmelo-Silver & Pfeffer, 2004; Linn et al., 2008; Roseman et al, 2008) moving from novices towards more expert understanding (Chi et al, 1981) because they could apply their understanding to explain the phenomenon. The other 50% of students were challenged with adjusting their claims. However, they also moved from less to more sophisticated understanding as evidenced by their understanding of science ideas increasing and their ability to connect those ideas with evidence also increasing, but they did not fully develop an integrated understanding because they were unable to align their claims with evidence and reasoning. In other words, they were not fully able to apply their understandings to explain the phenomenon.

7.7 Contributions and Implications for Research

A major goal of science education is to assist students to development useable knowledge structures, integrated understanding (Bransford, Brown, & Cocking, 2000; Fortus & Krajcik, 2011; Hmelo-Silver, & Pfeffer, 2004; Linn et al., 2008; Roseman et al., 2008), that allows them to explain various phenomena and to solve problems as part of being a scientifically literate citizen (Choi et al, 2011; National Research Council, 2012; National Science Education Standards 1996; OEDC, 2004). It is a challenge specified by the New Framework for K-12 Science Education (NRC 2012) in the United States. This study sheds light on how to support students toward developing a more sophisticated, integrated understanding of science with an emphasis on constructing complex evidence-based scientific explanations that allow them to move towards becoming scientifically literate. The significant learning gains exhibited by students in this study provide an example of what this process can look like as students build a rich explanation to tell the evidence-based science "story" of the health of a stream for freshwater organisms.

7.7.1 Supporting Students towards Developing Integrated Understanding

How to help students develop integrated understanding is a challenge that is investigated in the research community. Students understandings are often composed of nonintegrated, disconnected bits of information (NRC, 2001; Roseman et al., 2008). If students had integrated understanding they would be able to see connections between ideas and then use those relationships to solve problems or explain phenomena, as stated by Fortus and Krajcik (2011) and Kali, Linn, and Roseman (2008). Chi (2011), Hmelo-Silver and Pfeffer (2004), and Rottman and colleagues (2012) found that experts develop their knowledge around core concepts, that this knowledge is integrated because experts are able to use their understanding.

Constructing evidence-based explanations can assist students towards developing integrated understanding and is emphasized in many of the major science education documents that are designed to impact on practice (American Association for the Advancement of Science 2008; National Research Council, 2000; 2007; 2008). McNeill and colleagues (2006) showed that supporting students in developing explanations fosters learning in part, as Osborne (2014) argued. Scientific practices are cognitively demanding and they assist students to improve the quality of their learning. These experiences, however, are not what students typically experience (Obsorne, 2014).

In classrooms where students do engage in writing explanations, one area of challenge recognized by researchers is how to help students with reasoning, the portion of explanations which students find particularly demanding (Berland & Reiser, 2009; McNeill & Krajcik, 2006). Reasoning relates to what Fortus and Krajcik (2011) and Kali and colleagues (2008) refer to as *using* or *applying* understanding of relationships of science ideas. As Krajcik and Shin suggest (2013), and as is suggested in the New Framework for K-12 Science Education (2012), developing understanding of core ideas and crosscutting concepts through engagement in scientific practices, like constructing explanations, help students to understand the broader and deeper levels of scientific knowledge and how to make use of that knowledge. Although they go hand-in-hand, I propose in this research, that the reasoning portion of an explanation consists of two parts: science ideas and the connecting of those science ideas to evidence and, through this study, work to tease these two components apart and then put them back together. In fact, it could be argued that reasoning consists of three components: science ideas, connecting those science ideas to evidence, and then generating an appropriate claim based on the science ideas and connections. Perhaps, when students can successfully do all of these, will they then possess organized, usable knowledge and thus, truly have integrated understanding of the science concept under investigation and how to apply those understandings to explain phenomena and solve problems.

7.7.2 Integrated Understanding and Reasoning

Research from this study suggests, and what I believe to be a major finding of this research, that evolving explanations is one way to assist students to engage in reasoning as part of developing an integrated understanding that allows them to explain phenomena. An evolving explanation, writing various iterations where students revise work from previous iterations, and also include additional evidence, affords students multiple opportunities to revisit science ideas, to make more connections between ideas thus seeing more relationships, and then to incorporate how the evidence can be discussed using those science ideas. The research in this study sought to explore if each iteration helped students delve deeper into science ideas, thereby assisting them to organize their knowledge around core concepts (Chi, 2011; Hmelo-Silver & Pfeffer, 2004; Rottman, Gentner, & Goldwater, 2012) to apply those understandings to develop a more integrated understanding (Krajcik & Shin, 2013; Roseman, Linn, & Koppal, 2008).

Students in this study constructed an evolving explanation; four versions of an explanation that became progressively more complex as students collected more and more data from a stream. This process also aligns with nature of science ideas (NGSS 2013, Appendix H). I would make the case that the evolving explanation assisted students to develop integrated understanding. Like experts, based on research in this study, I would argue that through the process of constructing the evolving explanation about 50% of the students in this study became student experts who displayed well-developed knowledge structures, or integrated understanding, around ideas related to water quality and human impact on water quality (NGSS, 2013) that guide their thinking (Chi, Feltovich, & Glaser, 1981; Hmelo-Silver & Pfeffer, 2004; NRC 2007; NRC 2000). Their organized knowledge allowed these students to think about and then explain the complex phenomenon of the health of a local stream for freshwater organisms. They started as learners trying to explain phenomena using little to no science, with science ideas represented as fragmented bits of information (Roseman et al, 2008) and with no connections to evidence. Over the course of the evolving explanation, however, these students told an ever-increasing sophisticated science "story" of the health of the stream for freshwater organisms. They successfully used science ideas to discuss evidence, the reasoning portion of explanations that is most challenging (Berland & Reiser, 2009; McNeill & Krajcik, 2006) and then from these were able to generate an appropriate claim.

However, about 50% of students in this study did not fully develop an integrated understanding. I would argue that all of these students moved towards an integrated understanding; over the course of the four iterations, their work showed statistically significant effects, as did the others. They were all able to improve at generating science ideas and seeing relationships between science ideas. They improved at using science ideas to discuss evidence, thus also improved in their ability to reason. These statistically significant effects were in all areas but one. For various reasons, these students were challenged to generate an appropriate claim. Tables 6.7 and 6.8 summarize findings that show that claims were often not adjusted and only reflected evidence obtained early in the water quality explanations. Even though the overall explanation evolved over time, it appears that claims did not evolve, at least for about 50% of students. Claims are part of an explanation that are seen as most accessible to students (McNeill & Krajcik, 2011; Berland, & Reiser, 2009; McNeill & Krajcik 2007; McNeill et al 2006).

7.7.3. Adjusting Claims

Another finding from this study is that many students are challenged to adjust their claims. This result is inconsistent with current research that indicates claims to be the most accessible portion of explanations for students (Berland, & Reiser, 2009; McNeill & Krajcik 2007; 2011; McNeill et al., 2006). It could be argued that students ignored or discounted evidence (Chinn & Brewer 1993, 1998) that did not fit their thinking or they were not able to make a paradigm shift in the face of anomalous data (Kuhn, 1996). Perhaps these students simply could not “let go” when presented with these new situations as Brandsford and Schwartz found (2001). Before students could let go of current claims, perhaps a reflective, metacognitive component needed to be added to instruction (NRC, 2007, Choi et.al 2011). The research suggests that, for whatever reason, about 50% of students did not examine if their claim accounted for all available evidence (Duschl, 2007; Sampson & Clark, 2006).

Another question that arises from this study is why some students do not attend to all of the evidence when making claims, particularly since the evidence was discussed within the explanation. Are students challenged with adjusting claims in light of new evidence related to their science experiences or their educational experiences in general? Have they learned to complete one task and then move on to the next task? Even in classes where revision is often a component of the work, as in English classes, students begin with a rough draft, and then improve and expand on the original ideas. Similar to students in an English class revising a rough draft, students constructing an evolving explanation are improving on their original work (teacher feedback also included feedback about their evidence and reasoning). A difference though, is that the students are also incorporating new evidence that may drastically impact upon their overall explanation. Could it be that students do not have a view of science as an evidence-based field where ideas evolve over time - weeks, years, even decades and centuries - as new evidence emerges? If so, this would support the need to include more of a focus on nature of science in the curriculum (NGSS 2012, Appendix H). I do not have answers to these questions; this is one area for further research.

I have one final question related to why students might include some text related to additional evidence without incorporating it into a revised claim. I wonder if electronics inhibit or discourage students from cognitively engaging in the process. It may be that these digital natives do not reflect deeply on their thinking because digital tools enable them to easily copy, paste, add and delete text, and move text around. Could it be that students simply added the word "conductivity" to the original claim even though it resulted in a contradictory claim? Could they have followed directions to include a context for a third, and then later a fourth water quality test; they attended to these directions but either simply forgot to adjust their claim or did not attend to the more cognitively challenging task of rethinking their initial ideas? These are questions that arise from this research that I cannot answer; this is another area for further research. Perhaps this new research could include student interviews that may provide insights into the many possible reasons that some students are challenged to adjust claims.

7.7.4 Integrated Understanding and Evolving Explanations: Summary

Current research looks at how students write multiple explanations in a unit, each focusing on different phenomena (Cavagnetto, 2010). Students in the classrooms in this study engaged in writing an evolving explanation: four iterations of one explanation over time as new evidence was collected to explain a complex phenomenon. Although more research is needed to determine if writing "evolving explanations" when exploring complex phenomena assists students towards developing integrated understanding, this study provides insights into the process with promising results. A powerful finding is how multiple opportunities, a hallmark of an evolving explanation, allows students to revisit science ideas, to make more connections between ideas thus seeing more relationships, and to better connect science ideas with evidence, called reasoning. These are important components towards assisting students towards integrated understanding.

7.7.5 Three-Dimensional Learning

The Framework for K-12 Science Education in the United States (2012) introduces three dimensions: scientific and engineering practices, crosscutting concepts, and disciplinary core ideas. Developing learning experiences for classrooms should blend these three dimensions. This thesis provides a rich example of a project-based curriculum that is based on 3-dimensional learning as the methodology of instruction. Not many examples exist. As such, the curriculum itself as well as how it is used in this classroom, both from the teacher perspective and from the learning gains of the students contributes to the research community. As well, this study should inform the science education community, including teachers and curriculum developers, as they transition towards a 3-dimensional curriculum and teaching strategies. Using scientific practices, including constructing an evolving explanation, and crosscutting concepts of cause and effect, students in this study applied understanding of science ideas to explain a phenomenon, with an array of statistically significant effects, thus exhibiting the results of what 3-dimentional learning can accomplish. Additionally, the study broadens the field to explore students' constructing explanations within a context that aligns with the understandings about Nature of Science (NGSS 2013, Appendix H). Even with the one example in this study, however, many more learning experiences using 3-dimensional learning with curriculum that requires students to "operate at the intersection of practice, content, and connection" (NGSS 2013, p. xvi) need to be designed, and there is much research that needs to be carried out, not only with respect to students writing explanations and working towards developing integrated understanding, but in all aspects of teaching and learning related to goals of instruction using 3-dimensional learning.

7.7.6 Iterative Process, Scaffolding, Feedback, and Practice

The results of this study show that evolving explanations helped students develop rich understanding using an iterative process that was supported through teaching that used synergistic scaffolds, though not all students fully developed integrated understanding, particularly related to generating claims that were supported by all of the data (Duschl, 2007; Sampson & Clark, 2006). As such, the study also reinforces the literature that supports the value of developing curriculum with an iterative rather than sequential focus, over time, in order to help students develop an integrated understanding of science ideas, practices, and cross cutting themes (Fortus et al 2011; NRC 2010). Scaffolds allow students to engage in tasks that they would simply not be able to do on their own (Quintana, et al, 2004).

Constructing explanations in general is a challenging task. These students explored a complex phenomenon over a six-week period. The explanation they constructed was also complex and both developed and changed with time. Students needed lots of support and the teacher utilized several different supports and strategies. These supports and strategies are referred to as distributed scaffolds (Tabak 2004) and can work synergistically to assist students to build stronger understanding (McNeill & Krajcik, 2009; Quintana et al., 2004; Tabak, 2004). The focus of this study was not, however, on analyzing these scaffolds but rather, to analyze student development towards integrated understanding of a complex phenomenon. It has to be noted, though, that the teacher provided scaffolds to assist students. Looking closely at the various scaffolds used in these classrooms is another area of future research. For example, students utilized teacher-prepared guide sheets that included prompts for students to think about and then take notes to be used to write their explanations. How did students use these guide sheets? Did students use these guides in different ways? Did these guide sheets assist students?

Learning, in this study, was enhanced by teacher feedback to students about particular qualities of their work and what they could do to improve their understanding (Black, 2003; Pellegrino, Chedowsky & Glaser, 2001). Practice and feedback combined are critical to the development of skill and expertise (Pellegrino et al., 2001). Black found that focusing on what students need to know using written formative feedback, with a goal to assist students towards learning improves student performance (2003). The teacher in this study did just that, providing students with written, electronic feedback twice during the process, after Explanations #2 and #3, which students then used for revision. She also provided feedback after the final iteration, Explanation #4. Utilizing scaffolded guide sheets, providing students with feedback, and the iterative nature of the evolving explanation were all intentional instructional strategies that were utilized by the teacher. In addition to conducting further research to look at the scaffolds used in this curriculum, research to analyze the feedback provided to students and their response to that feedback may provide insights into how feedback promotes learning.

Developing a curriculum with evolving explanations provided students with a more authentic scientific experience that aligns with the Framework for K – 12 Science Education. Although more research is needed to determine if writing "evolving explanations" assists students to develop a more sophisticated understanding of science concepts, practices, and crosscutting concepts, this study provides insights into a process that was utilized by a teacher as part of her curriculum. As such, the study also builds on the literature that supports the value of developing a curriculum with an iterative rather than sequential focus, over time. The importance of practice and feedback are evidence in this study. Synergistic scaffolds were also an integral component in this curriculum. The purpose of these varied scaffolds was to work together to help students on a complex task that they would otherwise not have been able to accomplish (Bransford, et al,. 2000; Quintana, et al., 2004; Tabak, 2004; Wood, Bruner, & Ross, 1976). With a goal to assist students towards developing an integrated understanding, this curriculum provided students with experiences that blended science ideas, practices, and crosscutting concepts. Together these represent complex ideas and practices; with an iterative focus realizing that students need multiple opportunities (Fortus D. et al 2011; NRC 2010).

7.7.7 Transfer

Another significant finding of this study is related to transfer (Bransford, et al,. 2000; Bransford & Schwartz, 2001). This study's results show that once these grade 7 students had initial experiences and then included new evidence related to new science ideas, they incorporated appropriate and connected science ideas much more than in their earlier explanations. They were, in fact, prepared for future learning that allowed them to transfer their learning to new situations (Bransford & Schwartz, 2001). Student work for each water quality measured the first time they wrote about science concepts related to a specific water quality measure but after they were familiar with the explanation framework were compared. When students wrote about pH and temperature data (thermal pollution) they were novices to the practice of writing explanations. They also lacked science ideas that showed relationships and knowledge structures that prepared them to more fully utilize science ideas when incorporating new evidence and new science ideas into an existing explanation. When analyzing and initially writing about conductivity data, Explanation #3, and dissolved oxygen data, in Explanation #4, students were more familiar with the framework; they had received teacher feedback related both to the framework and to pH and temperature water quality science ideas. When doing pH and temperature for the first time, they had no "hooks" (or limited hooks) to understand the phenomenon. These two tests were part of the beginning of building a knowledge structure around water quality. Students were only beginning to develop a knowledge structure for water quality. The first time students included conductivity (the 3rd water quality measure) and dissolved oxygen concepts (the 4th water quality measure) into their explanations the number of science concepts they included were significantly higher than the numbers included the first time students incorporated pH and temperature reasoning (the first two water quality measures). These results can be found in Table 5.4 of Chapter 5. For conductivity and dissolved oxygen measures, students had a structure to which they could attach these ideas. All of these comparisons were made after the Explanation Framework was introduced.

The results suggest several ideas that inform the field. First, practice and feedback combined are critical to the development of skill and expertise (Pellegrino et al., 2001). The ideas of practice and feedback are not new. I believe, though, that results from this study within the context of a much more complex explanation, this evolving explanation, not only illustrates the importance of practice and feedback, but additionally provides a rich example of how practice and feedback fosters students towards greater synthesis when using new science ideas that result in more integrated understanding. Second, related to practice and feedback through the iterative process of constructing one evolving explanation, I think the large gains that students' exhibited illustrate students' preparedness for future learning (Bransford & Schwartz, 2001). These learning gains can be seen in Tables 5.4 of Chapter 5 and Table 6.2 of Chapter 6. The synergistic instructional moves in the first two iterations of the explanation assisted students to progressively build knowledge structures that prepared them for extended learning, in other words for transfer of learning. Several synergistic scaffolds utilized by the teacher worked together to assist students towards building understanding (McNeill & Krajcik, 2009; Quintana et al, 2011; Tabak, 2004). The context of this curriculum does not change; it is the water quality of a stream and human activities that impact upon it. The focus throughout is on the same phenomenon: there are water quality factors that either support or are not conducive for the survival of freshwater organisms. The situations to determine the water quality of the stream, the various water quality measures, do change. Each water quality measure includes science ideas. Analyses of students' scores on an end of the semester examination provide evidence that conductivity and dissolved oxygen concepts were not easier than pH and temperature concepts for students. Conductivity concepts may have been more challenging, in fact (see Chapter 5, Table 5.5). The results suggest that students were able to transfer their learning, both related to explanations and how to think more deeply about science ideas by making connections between them, as they gained more experience. I interpret these results to provide evidence that students were able to transfer their learning to new situations. They had developed a structure for thinking about and analyzing data using science ideas and it became easier to connect to this structure.

7.8 Limitations of the Study

The findings of this study indicate significant effects from eight of the nine research questions. While these results are promising, caution needs to be taken not to generalize based on this study alone. There are several limitations that may have impacted the results of my study.

One Teacher

All of the research conducted for this study was from students in four science classes that had the same teacher. The significant effects could be related specifically to the teacher rather than the use of an evolving explanation, the scaffolds, or the curriculum. Perhaps the personality of the teacher was highly motivating to students or had dramatic effects on students learning and accounted for the effects, rather than what was reported in this study.

Highly Motivated Students

Students in this study attended an independent school and were highly motivated to learn. Different results may have been obtained with students in public schools or in schools with less motivates students or more of a range of level of motivation.

One Curriculum

This study focused on one curriculum that utilized 3-dimensional learning as the methodology for instruction. The results from this study, while promising, are limited to this one curriculum and cannot be generalized based on one study.

Evolving Explanation

I am not aware of other research that investigates students constructing an evolving explanation over time. Again, while the results are promising, particularly related to students developing integrated understanding when explaining a complex phenomenon, the results cannot be generalized based on one study.

Limited Insight

A great deal of data were gathered and analyzed for this thesis. However, there were other data that could have been obtained that could have provided greater insight into student learning and student challenges; for practical reasons, though, not all could be included. For example, the scaffolded guide sheets could have been analyzed to explore their utility in assisting students. Student videos could have been obtained to capture conversations and insights as students worked with partners to take notes for their explanations. Student interviews could have provided insight into why students were challenged to adjust their claims. More in-depth analysis on the interplay between the student conversations with student partners when completing the scaffolded guide sheets could have been useful. Other additional data could include student utilization of teacher written feedback when revising explanations. Lastly, video of the teacher and her verbal scaffolding and feedback to students would provide insight.

7.9 Implications for Future Work

Additional studies that included more than one teacher, all using the same curriculum and strategies would assist to provide a higher confidence level to make generalizations. As well, conducting similar research in public schools that have students with a range of motivation for learning would provide more generalizable results. Investigating other curricula that used 3-dimensional learning and that also focused on students constructing explanations of complex phenomena would be valuable, particularly having students construct an evolving explanation as data is gathered over time. Other considerations that would provide greater insight into student learning include video-taping student conversations, student interviews to address challenges students face, particularly why students did not adjust their claims in light of new contradictory evidence. Students constructed explanations based on notes they generated with partners that were recorded on a scaffolded guide sheet that included various prompts to assist students. Analyzing these guide sheets could turn out to be very useful in gaining insight into student learning. As well, it could inform teachers as to how to best support students in these complex tasks.

7.10 Chapter Summary

The aim of this thesis was to explore the development of grade 7 students integrated understanding of a complex phenomenon and the learning environment and support that a teacher provided to support students in this undertaking. In these classes, students worked to explain a complex phenomenon, the health of a local stream for freshwater organisms, where they constructed an evidence-based scientific explanation, through four iterations, over a period of six weeks as more data were collected. This explanation was called an evolving explanation. Nine research questions were investigated and results indicated significant effects related to all but one research question. All students developed from novice towards expertise constructing more and more sophisticated understanding of the health of the stream by understanding more and more relationships between science ideas and connecting those understanding to evidence as part of reasoning. About 50% of the students were able to apply or use those understandings to generate appropriate claims. Thus, 50% of students in this study could be considered as having developed integrated understanding where they have organized their knowledge around core concepts (Chi, 2011; Hmelo-Silver & Pfeffer, 2004; Rottman, Gentner, & Goldwater, 2012) to apply those understandings to develop more integrated understanding (Krajcik & Shin, 2013; Roseman, Linn, & Koppal, 2008). The other 50% developed a great understanding of science ideas and connected those science ideas to explain their evidence, but were not able to use their understanding to generate an appropriate claim. Additional research into both of these types of student learners is needed to further explore the challenges and successes of developing integrated understanding.

The goal of research such as that presented in this thesis is to assist students to develop sophisticated understanding and to apply those understandings to explain phenomena, solve problems, and be prepared for future learning. If this goal is realized, students will possess organized, usable knowledge and move towards becoming scientifically literate citizens who are prepared to make decisions related to societal problems (Choi et al, 2011; National Research Council, 2012; National Science Education Standards 1996; OEDC, 2004).

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Appendix A

Water Project's 3-Dimensional Learning Ideas from the Framework/NGSS

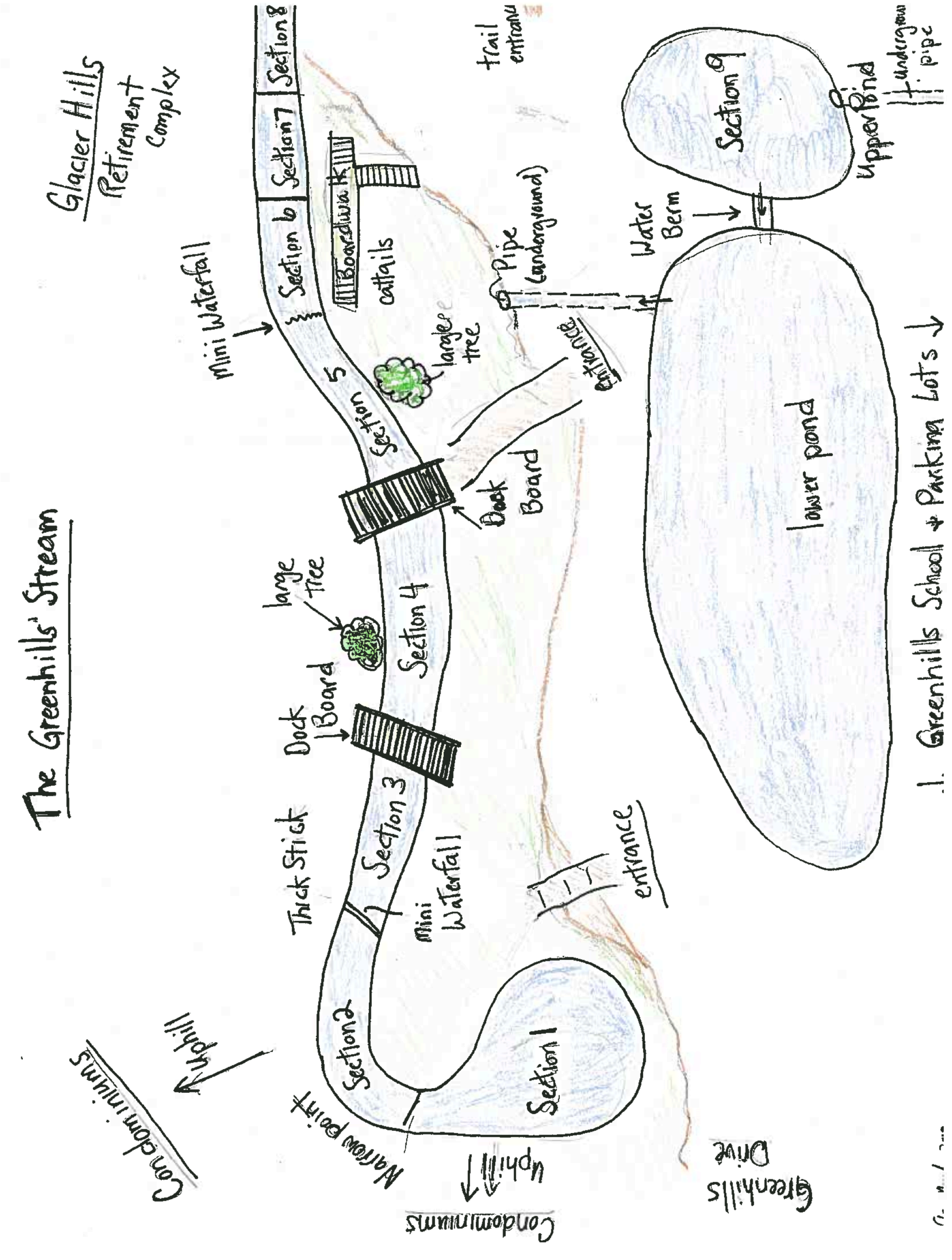
Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Practice 1: Asking Questions and Defining Problems. Practice 3: Planning and carrying out investigations Practice 4: Analyzing and interpreting data Practice 6: Constructing explanations Practice 7: Engaging in argument from evidence Practice 8: Obtaining, evaluating, and communicating information	**MS-LS2 Ecosystems: Interactions, Energy, and Dynamics** LS2.A: Interdependent Relationships in Ecosystems • Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with non-living factors (MS-LS2-1) • In any ecosystem, organisms and populations with similar requirement for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. (MS-LS2-1) • Growth of organisms and population increases are limited by access to resources. (MS-LS2-1) • Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and non-living, are shared. (MS-LS2-2)	**1. Patterns**. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them. **2. Cause and Effect: Mechanism and explanation.** Events have causes, sometimes simple, sometimes multi-faceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain
	LS2.B: Cycle of Matter and Energy Transfer in Ecosystems • Food webs are models that demonstrate how matter and energy are transferred between producers, consumers, and decomposers as the	events in new contexts. **4. Systems and system models:** Defining the system under

	three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and non-living parts of the ecosystem. (MS-LS2-3)	study-specifying its boundaries and making explicit a model of that system-provide tools for understanding and testing ideas that are applicable
	LS2.C: Ecosystem Dynamics, Functioning, and Resilience • Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations. (MS-LS2-4) • Biodiversity describes the variety of species found in Earth's terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health. (MS-LS2-5)	throughout science and engineering. **7. Stability and change.** For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a
	MS-ESS2 Earth's Systems ESS2.C: The Roles of Water in Earth's Surface Processes • Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land. (MS-WW2-4)	system are critical elements of study.
	MS-ESS3 Earth and Human Activity ESS3.A: Natural Resources • Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geological processes.	

	(MS-ESS3-1) ESS3.C: Human Impacts on Earth Systems • Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. (MS-ESS3-3) • Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth, unless the activities and technologies involved are engineered otherwise. (MS-ESS3-3), (MS-ESS3-4)	

Appendix B

The Greenhills Stream with Stream Sections for Various Teams



Appendix C

Guide Sheet for Explanation #2 Name:____________________

Water Quality Fall Scientific Explanation- Work Sheet

Fill in each box with notes from your data, background, and predictions. Next, use these notes to write up a complete explanation for the health of our stream so far.

Title: Stream Section __ Explanatio		
Introduction – a couple of Sentences: set context		
Make a **CLAIM** How healthy? Standard? Can organisms live?		
Provide **EVIDENCE** to support your claim (Your pH & Temp. difference from of each locat Provide evidence from physical Observation.	1a.	2a.
REASONING: explain and discuss Results – WHAT do they MEAN?: Use scientific concepts from background information - Causes and consequences with your evidence (Test results, physical data sheet, and graphs). **What** do the results Mean? Consequences. Standard. Are these results positive Or negative? Why? **Why** did you get these results? Incorporate the causes completely discuss/explain- Use info. from pH and Temperature (hand-outs)s	1b.	2b.
Rebuttal: Is there another possible Cause or consequence that you didr Use to explain? What is it? Why Didn't you choose it (them?)?	1c.	2c.
Compare your results with your Predictions. Discuss	1d.	2d.
Conclusion. Wrap up the Section. Include an ACTION STEP (or two) for each test. What Can people do?	3.	3.

Appendix D

Guide Sheet for Explanation #3

Name:____________________

Water Quality Explanation Outline – 3 pieces of evidence

Introduction {Set the context for the study. Each test: What is it? Why is it important? *Add to your current introduction.*

Claim {Statement: Answers the question about the stream's health. Includes standard and if organisms can live or not. *Do you need to change your current claim?*

Evidence {Add your conductivity data from each location. Other qualitative data from physical data Sheet. *Put this after your temperature information.*

Reasoning { What do the results mean? Use science ideas

Are they positive or negative? Why? What are the sources of dissolved solids (P, N, and S) What are the consequences?

Why do you think you got these results?

Use the science to discuss your results – this will tie the science, your results and your physical data together.

Rebuttal { Is there an alternative explanation or reason that you did not choose? Why not?

Prediction? {How did your predictions compare with your results?

Conclusion {Statement: General wrap-up: standard and if organisms can live based on 3 pieces of evidence. Summary of specific WQ tests with standard. Hooks back to the claim. Include an ACTION STATEMENT for the conductivity test (in addition to the pH and temperature action steps you already have in your explanation) – What can people do?

Name:________________________________

Water Quality Explanation work sheet: Conductivity (3rd piece of evidence)

Introduction {

Claim {

Evidence {

Reasoning {

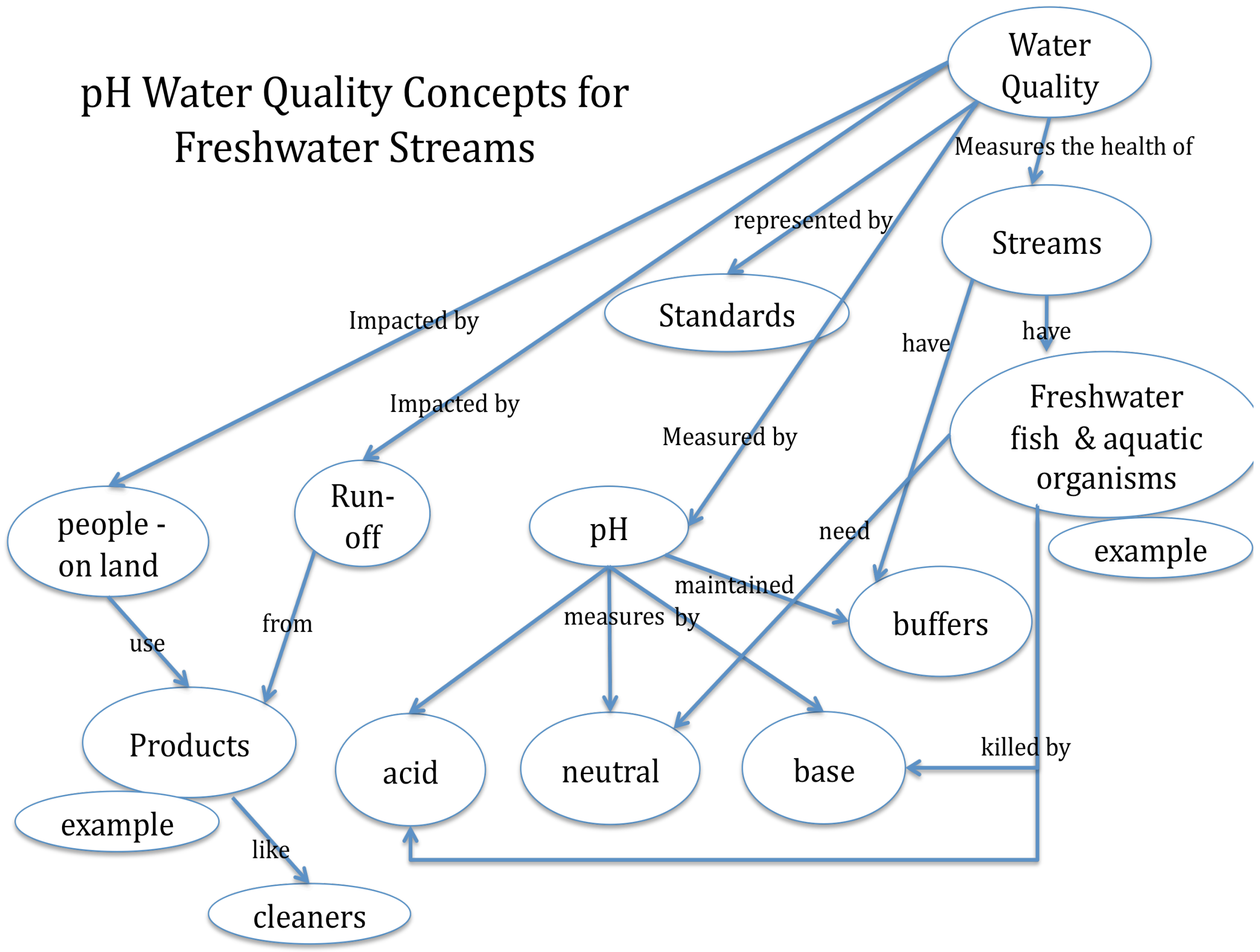
Rebuttal {

Prediction? {

Conclusion {

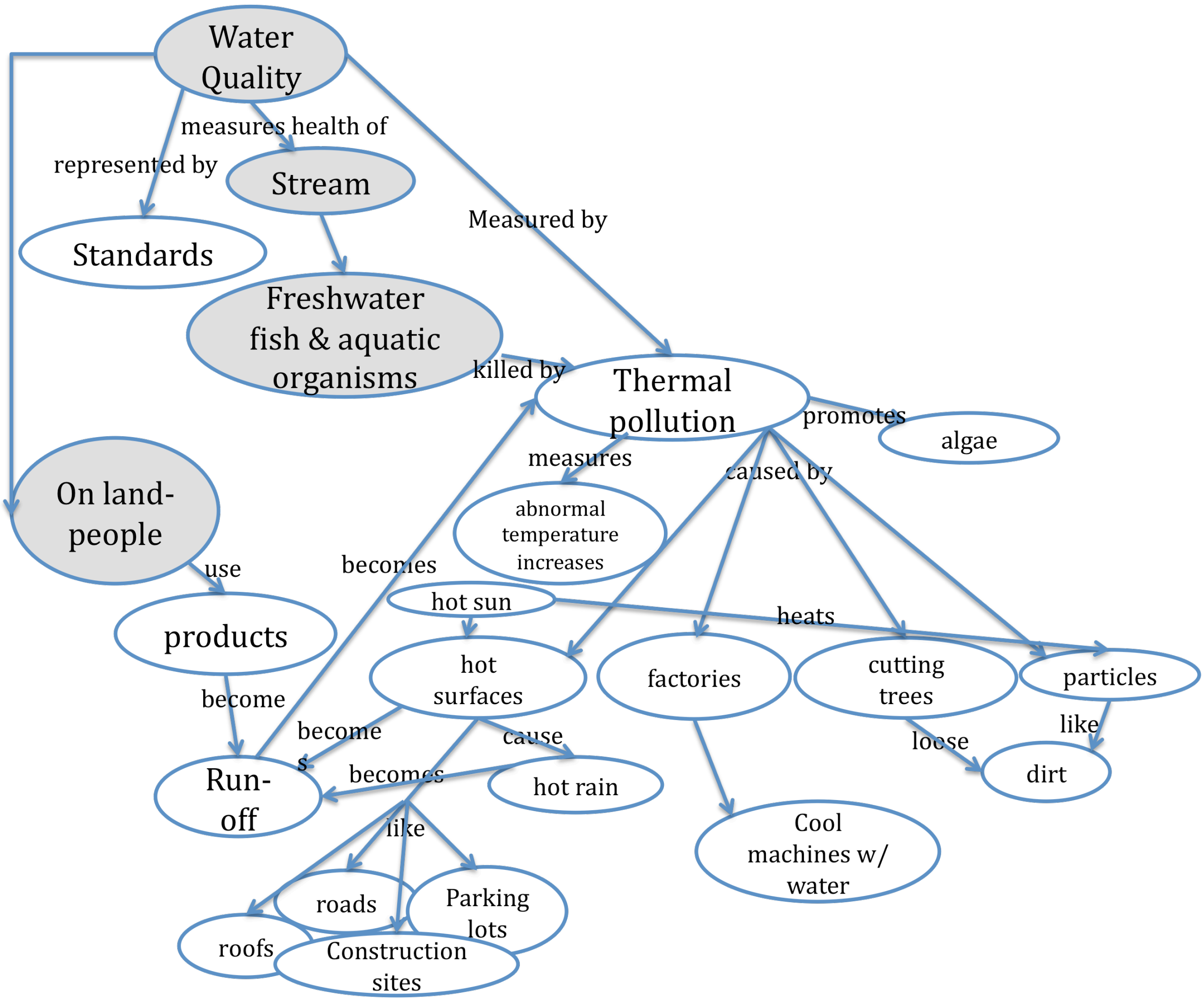
Appendix E

Concept map of pH Water Quality Science Ideas



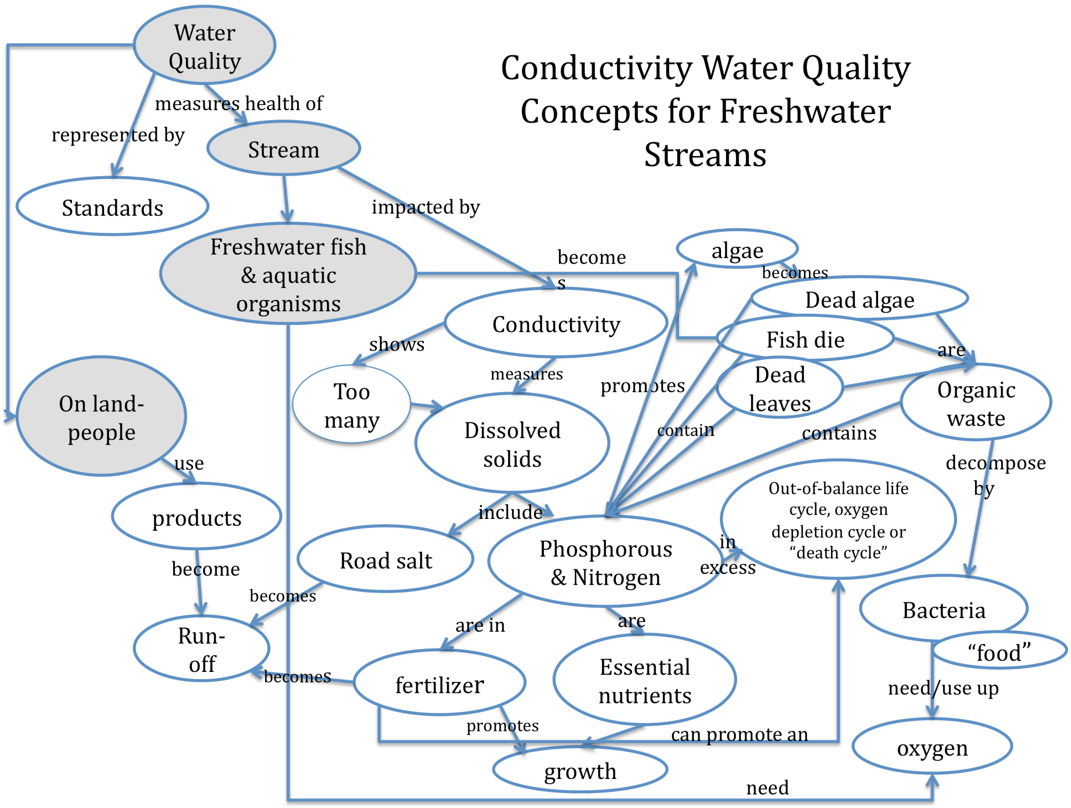
Appendix F

Concept Map of Temperature Water Quality Science Ideas



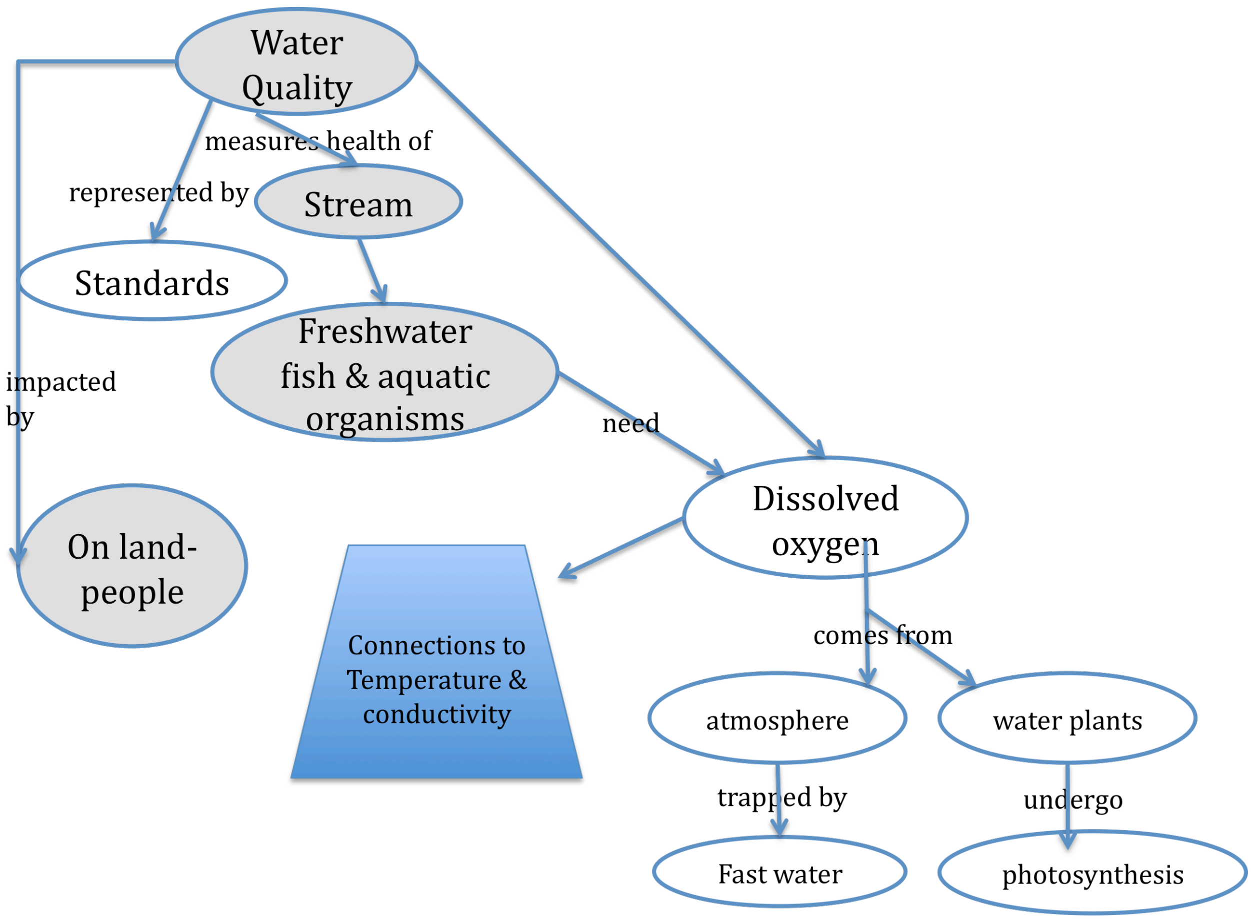
Appendix G

Concept Map of Conductivity Water Quality Science Ideas



Appendix H

Concept Map of Dissolved Oxygen Concepts



Appendix I

Rubric for Explanation #4: "How Healthy is Greenhills' Stream?" – 4 pieces of evidence

Claim (C)	Evidence (E)	Reasoning (R)	Rebuttal (Re)	Action Step (A)
__0__ CA. Does not make a claim or makes an inaccurate claim.	__0__ EA Does not provide evidence or only provides inappropriate evidence.	__0__ RA. Does not provide reasoning or provides inappropriate reasoning.	__0__ Re. Does not recognize an alternative explanation exists or make an inaccurate rebuttal	__0___ (AA) Does not provide an action step and how that action step will help
__1__ CB. Makes a vague claim __2__ CC. Claim includes only one of the following: Stream's health for organisms **OR** Standard or combination of standards __3__CD.	Provides quantitative data and at least 2 pieces of qualitative evidence for all 4 Water quality tests & evidence supports the claim **pH Evidence:** __2__ EB. Quantitative *(Includes numbers at all 3 locations or summarizes numbers at all locations = 2. **or** Only reports numbers at one location w/o referencing other locations -= 1)* __2__ EC. Qualitative *(ie soap bubbles, nearby*	Provides all reasoning components: WHAT evidence means and WHY these results? Connects reasoning to evidence for each WQ test. **pH Reasoning** __1__ RB. stream is acidic? Basic? Neutral? correct __1__ RC. Correct Standard –*most neutral a couple slightly basic (excellent or good – a couple fair)* positive results: __1__ RD. Most organisms need neutral pH: will die __1__ RE. Ex: name of organisms and pH range needed __1__ RF. Ex. - product and pH from land-use run-off __1__ RG. Buffers – define Connects pH reasoning to pH evidence __0__ RH. No connection* __1__ RI. Vague connection* choose one* __2__ RJ. Clear connection*	Recognizes and describes **at least one** alternative explanation and why alternative explanation is not appropriate – one rebuttal per WQ test **pH rebuttal** __0__ ReA. No rebuttal or inaccurate rebuttal __1__ ReB. Attempt's rebuttal __2__ ReC. Accurate rebuttal *(ex: products from land-use run-off into stream; not occurring now or buffers working, acid rain: stream is not acidic)*	Provides one action step and discusses why that will help *(something to stop doing, continue to do, or to avoid)* pH action step __0__ AB No action step __1__ AC action step no reason __2__ AD action step with reason

Claim includes BOTH stream's health for organisms **&** Standard **PLUS** __1__ CE. Claim utilizes 1 piece of evidence __2__ CF. Claim utilizes 2 pieces of evidence __3__ CG. Claim utilizes 3 pieces of evidence __4__ CH. Claim utilizes 4 pieces of	*sources – homes, windows, roads, etc)* temperature differences: __2__ ED. Quantitative *(Includes numbers at all 3 locations or summarizes numbers at all locations = 2.)* ***Or*** *Only reports numbers at one location w/o referencing other locations -= 1)* __2__ EE. Qualitative *(ie surfaces, particles, shade)* conductivity Evidence: __2__ EF. Quantitative *(Includes numbers at all 3 locations or summarizes numbers at all locations = 2.)* ***Or*** *Only reports numbers at one location w/o referencing other locations -= 1)*	Temperature differences: __1__ RK. No thermal pollution/abnormal temp inc __1__ RL. Correct Standard – *(excellent or good)* <u>Positive results</u>: If thermal pollution: __1__ RM. fish die __1__ RN. promotes algal bloom __1__ RO. can hold less D.O., __1__ RP. sick fish <u>Reasons for results?</u> __1__ RQ. Weather – too cold *(November)* ---→ __1__ RR. particles not heating up __1__ RS. surfaces not heating up <u>Connects Temp reasoning to temp evidence</u> __0__ RT. No connection* __1__ RU. Vague connection* choose one* __2__ RV. Clear connection* Conductivity Reasoning: __1__ RW. too many dissolved solids __1__ RX. Correct standard: poor (a couple w fair) <u>possible causes (reasons)</u>: __1__ RY. N & P from organic waste __1__ RZ. N & P fertilizer: essential nutrients--- *P from soap??* <u>Negative results:</u> __1__ RAA. N & P – promotes algal bloom – __1__"RBB. Death cycle" __1__ RCC. Death cycle explained: dead algae food for bacteria, bacteria population increase, bacteria	Temp. Difference rebuttal __0__ ReD. No rebuttal or inaccurate rebuttal __1__ ReE. Attempt's rebuttal __2__ ReF. Accurate rebuttal *(ex: no factories to dump not water, weather – too cold particles/surfaces could heat in warmer weather* Conductivity Rebuttal: __0__ ReG. No rebuttal or inaccurate rebuttal __1__ ReH. Attempt's rebuttal __2__ ReI. Accurate rebuttal *(ex. high conductivity could be due to road salt. No snow yet.* ***<u>OR</u>*** *explicitly states no rebuttal – N, P, S all contribute to results)*	<u>temp action step</u> __0__ AE No action step __1__ AF action step no reason __2__ AG action step with reason <u>Conductivity action step</u> __0__ AH No action step __1__ AI action step no reason __2__ AJ action step with reason

evidence PLUS __0__ CI. Evidence not synthesized into one claim (conductivity & D.0. not integrated w pH/Temp) __1__ CJ. Evidence partially synthesized into one claim __3__ CK. All Evidence synthesized into one claim	__2__ EG. Qualitative *(ie soaps, lawns, homes (algae – some)????* Dissolved O_2 evidence: __2__ EH. Quantitative *(Includes numbers at all 3 locations or summarizes numbers at all locations = 2).* ***Or*** *Only reports numbers at one location w/o referencing other locations -= 1)* __2__ EI. Qualitative *(ie stream flow, water plants, specific organic waste)*	use up O_2, fish die from lack of O_2 Connects Conduct. reasoning to conduct. evidence __0__ RDD. No connection* __1_ REE. Vague connection* choose one* __2__ RFF. Clear connection* Dissolved O_2 (D.O.) Reasoning: __1__ RGG. Enough oxygen for fish __1__ RHH. Correct Standard – *excellent or good (for most)* Reasons: __1__ RII. recent rainy weather – stream flow – fast water captures O2 from atmosphere __1__ RJJ. cold water can hold more D.O. __1__ RKK. cold weather/water – less bacteria to use up D.O. *(lots of organic waste for bacteria)* Positive results: __1__ RLL. Fish need oxygen to live --1—RMM. Stream Flow: fast water 0_2 from air --1—RNN. Water Plants: produce 0_2 --1—R00. Organic Waste: impacts D.O. (death cycle). Connects D.O. reasoning to D.O. evidence __0__ RMM. No connection* __1_ RNN. Vague connection* choose one* _ __2__ ROO. Clear connection*	Dissolved O_2 Rebuttal: _0__ ReJ. No rebuttal or inaccurate rebuttal __1__ ReK. Attempt's rebuttal __2__ ReL. Accurate rebuttal *(ie. D.O. could be from water plants but too cold for plants).*	Dissolved oxygen action step __0__ AK. No action step __1__ AL. action step no reason __2__ AM. action step with reason

Appendix J

Claims Scoring Rubrics for Explanations

Explanations #1 & #2 Claim (C)	Explanation #3 Claim (C)	Explanation #4 Claim (C)
__0__ CA. Does not make a claim or makes an inaccurate claim.	__0__ CA. Does not make a claim or makes an inaccurate claim.	__0__ CA. Does not make a claim or makes an inaccurate claim.
__1__ CB. Makes a vague claim	__1__ CB. Makes a vague claim	__1__ CB. Makes a vague claim
__2__ CC. Claim includes only one of the following: Stream's health for organisms **<u>OR</u>** Standard or combination of standards	__2__ CC. Claim includes only one of the following: Stream's health for organisms OR Standard or combination of standards	__2__ CC. Claim includes only one of the following: Stream's health for organisms **<u>OR</u>** Standard or combination of standards
__3__CD. Claim includes BOTH stream's health for organisms & Standard **<u>PLUS</u>** __1__ CE. Claim emerges from 1 piece of evidence __2__ CF. Claim emerges from 2 pieces of evidence <u>PLUS</u> __0__ CI. pH & temp Evidence not synthesized into one claim __1__ CJ. Evidence partially synthesized into one claim __3__ CK. Evidence synthesized into one claim	__3__CD. Claim includes BOTH stream's health for organisms & Standard **<u>PLUS</u>** __1__ CE. Claim utilizes 1 piece of evidence __2__ CF. Claim utilizes 2 pieces of evidence __3__ CG. Claim utilizes 3 pieces of evidence	__3__CD. Claim includes BOTH stream's health for organisms **&** Standard **<u>PLUS</u>** __1__ CE. Claim utilizes 1 piece of evidence __2__ CF. Claim utilizes 2 pieces of evidence __3__ CG. Claim utilizes 3 pieces of evidence __4__ CH. Claim utilizes 4 pieces of evidence <u>PLUS</u> __0__ CI. Evidence not synthesized into one claim (conductivity & D.0. not integrated w pH/Temp) __1__ CJ. Evidence partially synthesized into one claim __3__ CK. All Evidence synthesized into one claim
	<u>PLUS</u> __0__ CI. Evidence not synthesized into one claim (conductivity not integrated w pH/Temp) __1__ CJ. Evidence partially synthesized into one claim __3__ CK. All Evidence synthesized into one claim	