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Examining the integration of talk and writing for student knowledge construction through argumentation

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EXAMINING THE INTEGRATION OF TALK AND WRITING FOR STUDENT KNOWLEDGE CONSTRUCTION THROUGH ARGUMENTATION

by

Ying-Chih Chen

An Abstract

Of a thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Science Education
in the Graduate College of
The University of Iowa

July 2011

Thesis Supervisors: Assistant Professor Soonhye Park
Professor Brian Hand

ABSTRACT

The purpose of this study was to examine students' understanding of argumentation when talk and writing were provided as learning tools, as well as to explore how talk and writing can best support students' construction of scientific knowledge. Most current studies have examined discourse patterns over a short interval of only a few class periods or compared only the students' initial and final products to assess the quality of their argument structure. Few studies have examined how students develop their understanding of argumentation over time and how their understanding might result in overcoming those challenges. Moreover, talk and writing have been offered as two critical learning tools to support students' argumentative practice. So far, few studies have explored how those two learning tools could be combined to better support students in constructing scientific knowledge. The research questions that guided this study were: (1) How do students develop an understanding of the components of argumentation for public negotiations over time when participating in an argument-based inquiry classroom? (2) In what ways do talk and writing support scientific knowledge construction in an argument-based inquiry classroom?

This sixteen-week study was grounded in interactive constructivism and utilized qualitative design to identify students' understanding of argumentation, trace their learning trajectories, examine potential use of the combination of talk and writing, and analyze the cognitive processes involved when talk and writing were used as learning tools. Due to the lack of studies that focus on the elementary level, this study was conducted in a fifth-grade classroom that used the Science Writing Heuristic (SWH) approach with 22 students participating. Six students were selected for interviewing intensively. Multiple sources of data were collected, including classroom observations, semi-structured interviews, students' writing samples, and the researcher's field notes. To strengthen the interpretations, data analysis was conducted using three different approaches: (1) the constant comparative method, (2) the enumerative approach, and (3) in-depth analysis of knowledge construction trajectory (KCT) episodes.

The results showed that as fifth-grade students had more opportunities to practice, they could develop a more sophisticated understanding of argumentation, use talk and writing as learning tools to negotiate their ideas with peers, engage in more complex cognitive processes, and take ownership for their learning in science. Three major findings are discussed: (1) increased understanding of argumentative components in public negotiations, (2) increased ability to craft written arguments, and (3) five patterns in the use of talk and writing for knowledge construction and cognitive processes.

The findings have informed theories about argumentative practice, the use of language as a learning tool, and science learning from six aspects: (1) understanding of argumentation, (2) ability to craft written arguments, (3) use of talk and writing, (4) cognitive processes, (5) meaning of negotiation, and (6) methodology consideration. This study provides insights into the design of an argument-based environment in which students can develop successful argumentative practices. A long-term professional development program in the support of teachers implementing argument-based inquiry is suggested.

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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

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ABSTRACT

The purpose of this study was to examine students' understanding of argumentation when talk and writing were provided as learning tools, as well as to explore how talk and writing can best support students' construction of scientific knowledge. Most current studies have examined discourse patterns over a short interval of only a few class periods or compared only the students' initial and final products to assess the quality of their argument structure. Few studies have examined how students develop their understanding of argumentation over time and how their understanding might result in overcoming those challenges. Moreover, talk and writing have been offered as two critical learning tools to support students' argumentative practice. So far, few studies have explored how those two learning tools could be combined to better support students in constructing scientific knowledge. This study has been conducted to address these gaps in the existing literature. The research questions that guided this study were: (1) How do students develop an understanding of the components of argumentation for public negotiations over time when participating in an argument-based inquiry classroom? (2) In what ways do talk and writing support scientific knowledge construction in an argument-based inquiry classroom?

This sixteen-week study was grounded in interactive constructivism and utilized qualitative design to identify students' understanding of argumentation, trace their learning trajectories, examine potential use of the combination of talk and writing, and analyze the cognitive processes involved when talk and writing were used as learning tools. Due to the lack of studies that focus on the elementary level, this study was conducted in a fifth-grade classroom that used the Science Writing Heuristic (SWH) approach with 22 students participating. Six students were selected for interviewing intensively. Multiple sources of data were collected, including classroom observations, semi-structured interviews, students' writing samples, and the researcher's field notes. To strengthen the interpretations, data analysis was conducted using three different approaches: (1) the constant comparative method, (2) the enumerative approach, and (3) in-depth analysis of knowledge construction trajectory (KCT) episodes.

The results showed that as fifth-grade students had more opportunities to practice, they could develop a more sophisticated understanding of argumentation, use talk and writing as learning tools to negotiate their ideas with peers, engage in more complex cognitive processes, and take ownership for their learning in science. Three major findings consistent with eight themes are discussed: (1) increased understanding of argumentative components in public negotiations, (2) increased ability to craft written arguments, and (3) five patterns in the use of talk and writing for knowledge construction and cognitive processes.

The findings have informed theories about argumentative practice, the use of language as a learning tool, and science learning from six aspects: (1) understanding of argumentation, (2) ability to craft written arguments, (3) use of talk and writing, (4) cognitive processes, (5) meaning of negotiation, and (6) methodology consideration. This study provides insights into the design of an argument-based environment in which students can develop successful argumentative practices. A long-term professional development program in the support of teachers implementing argument-based inquiry is suggested.

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CHAPTER ONE

INTRODUCTION

Argumentation in School Science

Preparing students to be scientifically literate is the major goal of science education (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996, 2007). An essential element of this goal is to ensure that students are involved in science inquiry processes in which argumentative language is developed to make sense of data and then presented to a community of peers for critique, debate, and revision (Abd-El-Khalick et al., 2004; Dusch & Osborn, 2002; Hand, 2008; Sandoval & Reiser, 2004; Zembal-Saul, 2009). Learning science is no longer about replicating the language of science—using the big words of science without necessarily understanding their meaning—but rather involves engaging students in the argumentative processes of understanding what constitutes evidence, and asking them to link questions, claims, and evidence together to form strong scientific arguments. Consequently, argumentation is now seen as a core practice and goal for making students scientifically literate (Cavagnetto, 2010; Braaten & Windschitl, 2011).

Practices of argumentation have recently been upheld as a critical need for science instruction, and researchers have examined the outcomes of these argumentative practices (Berland & Reiser, 2010; Driver, Newton, & Osborne, 2000; D. Kuhn, 1993; Sandoval & Millwood, 2005). Most of these studies have focused on evaluating the value and structure of students' arguments, usually in terms of Toulmin's (1958) argumentative structure of claim, grounds, warrant, backing, qualifier, and rebuttal. These scholars further indicate that learning how to use arguments in particular environments is not something that occurs in a short period of time (Osborne, Erduran, & Simon, 2004). Moreover, they suggest that fostering productive scientific argumentation in classrooms is difficult and challenging because students often struggle with tasks that require them to present, critique, debate, and revise ideas (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Sadler, 2004; Sampson & Clark, 2009).

However, most current studies have examined discourse patterns only over a short interval of a few class periods (e.g., McNeill & Pimentel, 2010). Although some studies have been conducted over a longer time period, they have only compared students' initial and final products to examine changes in the quality of the arguments (e.g., Kelly & Chen, 1999; Ruiz-Primo et al., 2010; Sampson, Grooms, & Walker, 2011; Wilson, Taylor, Kowalski, & Carlson, 2010). Little research explores the process of students' development of argumentative practice over time. Those studies that point out the challenges and difficulties of argumentative practice have contributed greatly to the field of science education. However, to learn better how to support students in this argumentative practice and to overcome the challenges, an examination of the process is needed. In addition, little is known about the core components of argumentation[1] that support the development of students' understanding of arguments[2] and knowledge construction as well as of how students' understanding of these core components develops over time. It is uncertain whether students are able to transfer their argumentative abilities and skills from one context to another (Cavagnetto, 2010; Perkins & Salomon, 1989).

Given the importance of argumentation for science learning and the gap in current research, the purpose of this study is to examine the core components of argumentation demonstrated by fifth graders engaged in an argument-based inquiry environment in two science units over sixteen weeks.

Language in Argumentation

Current research indicates that learning how to engage in productive scientific argumentation to build and propose knowledge is difficult for students (McNeill,

[1] Argumentation in this study refers to the process of constructing the structure of arguments (Driver, Newton, & Osborne, 2000).

[2] Argument in this study refers to the product, consisting of three components: question, claim, and evidence (Hand, 2008).

Lizotte, Krajcik, & Marx, 2006; Osborne, Erduran, & Simon, 2004; Sandoval, 2005). Many scholars advocate strongly the need to create environments where students can talk in order to construct explanations, models, and theories just as scientists use arguments to relate the evidence they generate to claims (Lemke, 1990; Martin & Hand, 2009; McNeill & Pimentel, 2010; Prawat, 1993). Nevertheless, Yore and Treagust (2006) argue that although talk is necessary for argumentation, it is "not sufficient to do and learn science" (p. 296). They note that writing also plays an important role during argumentative processes. This view echoes Sweight's assertion that talking and writing are highly interconnected (1991). Wallace (2007) succinctly concludes that: "talk is most important for distributing knowledge, while writing is important for manipulating, consolidating, and integrating knowledge" (p. 11). A combination of talk and writing can aid student argumentation, in which writing can promote detailed connections among data, background information, claims, evidence, and warrants as well as reveal patterns of events. Talking and writing are therefore complementary learning tools for argumentative practice.

In this regard, talk and writing, used separately, may not be quite as useful as a strategy that combines them to obtain the benefits of both learning tools (Cavagnetto, Hand, & Norton-Meier, 2009; Rivard, 2004; Sweight, 1991; Yore & Treagust, 2006). However, studies in the field of argumentation often investigate talk and writing separately and disconnect their relationship in the argumentative process. For example, some researchers emphasize the impact of engaging students in talking within groups or as a whole class (Albe, 2008; Erduran, Simon, & Osborne, 2004; Jimenez-Aleixandre et al., 2000; McNeill & Pimentel, 2010), while others focus on the important mechanisms for individually scaffolding the construction of written arguments by students (Choi et al., 2010; Kelly, Regev, & Prothero, 2008; Takao & Kelly, 2003). At present, little research has investigated how talk and writing combined can best support students' construction of scientific knowledge through argumentation as well as what kinds of cognitive processes might be facilitated by the combination of talk and writing (Dysthe, 1996; Rivard, 2004). In response to this research deficit, this study has also attempted to explore in what ways students use talk and writing as learning tools to construct scientific knowledge and what kind of cognitive processes are involved.

Argumentation at the Elementary Level

Given the importance of argumentation for learning science, it is unfortunate that elementary school students usually have difficulty interpreting data to generate evidence, coordinating evidence and claims, and debating their claims in public (Cavagnetto, Hand, & Norton-Meier, 2009; Martin & Hand, 2009). Developmental psychologists who study children in natural settings during disputes or negotiations have reported that children have difficulty evaluating evidence and their judgments are biased by their own standpoint (Kuhn, 1991, 2001). To date, much of the research on argumentation in science classrooms has focused on the secondary level (Chin & Osborne, 2008; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Kerlin, Mcdonald, & Kelly, 2010; McNeill, 2009; Sampson & Clark, 2009; Scott, Mortimer, & Aguiar, 2006) or the college level (Kelly & Takao, 2002), and few studies have explored the situation of argumentation at the elementary level (Cavagnetto, Hand, & Norton-Meier, 2009). With this in mind, this study examines the argumentative process and the integration of talk and writing in a fifth grade elementary science classroom.

Purpose of the Study

The study presented here aims (1) to gain a better understanding of how fifth grade students develop their understanding of the nature of argumentation in an argument-based inquiry environment while learning two science units over sixteen weeks, and (2) to identify the patterns of talk and writing that emerge as the students construct understandings of scientific concepts.

The purpose of this study is not to decide which learning tool, talk or writing, is primary in knowledge construction. Rather, it is to understand how talk and writing can be combined to foster students' understanding of argumentation and, ultimately, to promote students' conceptual growth. This point can be clarified via an analogy to physicists' theories of light. Neither particle theory nor wave theory alone is sufficient to explain the characteristics of light. It is advantageous for physicists to consider light as both a particle and a wave. Coordinating the findings that derive from each perspective has led to advances in the field. Similarly, the assumption that underlies this study is that it is useful to consider how both talk and writing are used by students in argument-based inquiry classrooms to obtain a better understanding of students' conceptual development.

It has been claimed that the level or degree of understanding and engagement in argumentation for students is affected by the use of various language-based activities (Cavagnetto et al., 2009). Many researchers assert that it is better to integrate these two learning tools to improve students' arguments as opposed to using either talk or writing alone in argument-based inquiry (Hand, 2008; McNeill & Pimentel, 2010; Rivard, 2004; Rivard & Straw, 2000; Yore & Treagust, 2006). However, there are insufficient empirical studies that explain how talk and writing work together to promote students' argumentation or their knowledge construction and cognitive processes.

Research Questions of the Study

The research questions that guide this study are as follows:

1. How do students develop an understanding of the components of argumentation for public negotiations over time when participating in an argument-based inquiry classroom?
2. In what ways do talk and writing support scientific knowledge construction in an argument-based inquiry classroom?

Rationale of the Study

Argumentation is often discussed as a fundamental discourse of science and its use is advocated in scientific inquiry-based classrooms. Most of the studies in argumentation have focused on the final products, outcome, and the value of argument and argumentation (Sampson, Grooms, & Walker, 2011). Duschl and Osborne (2002) suggested that teaching science as argumentation must address epistemic goals that focus on *how we know what we know*, rather than simply *what we know*. Hence, it is important to understand the conditions and processes of how students coordinate claims and evidence during argumentative processes, instead of merely examining the final products of knowledge. At present, little is known about the process of argumentative practice and how students develop their understanding of the nature of argumentation over time. In addition, most research has focused on students' final achievements and outcomes in one unit (e.g. McNeill & Pimentel, 2010). Little research has investigated whether students are able to transfer their argumentative skills to another unit, thus continuously building their abilities. This study aims to fill the gaps in the literature and advances the understanding of the argumentative process and the transfer of argumentative skills.

Many researchers in argumentation fields have recognized the problem of separating talk and writing from argumentative processes and have tried to design learning environments that combine these two learning tools. However, most studies that have investigated the effect of argumentation have only focused on one learning tool. The exceptions are studies conducted by Rivard and Straw (2000) and Rivard (2004). Yet, their research was quantitative and still focused on the outcome of knowledge acquisition. The patterns of the combination of talk and writing that support students' knowledge construction and cognitive processes still remain unknown.

Furthermore, most of the studies that investigated students' argumentative practices have focused on the secondary school or college level. To date, only a few studies have focused on elementary school. This study attempts to understand how elementary school students at grade five construct their knowledge via utilizing talk and writing as learning tools over sixteen weeks.

The findings of this study are valuable for both theory and practice. This research aims to advance theories about learning and teaching argumentation that could be practically applied in various educational settings. Through exploring fifth graders' use of talk and writing to construct scientific knowledge through argumentative processes, this study expands the scope of the existing literature on student science learning through argumentation at all school levels, including the elementary school context. It also provides theoretical insights into the value of using talk and writing together in science learning. Additionally, this study suggests implications for teachers when designing argument-based science classrooms using talk and writing in order to understand the relationship between the use of the learning tools and student knowledge construction.

Overview of the Study

In this chapter, the rationale for studying elementary school students' argumentative practices via the combination of talk and writing as learning tools in argument-based inquiry classrooms has been addressed. The research questions and the significance of the study have also been indicated.

Chapter Two discusses the critical role of argumentation in science education and two different perspectives on language practices for promoting students' scientific knowledge construction: (1) learning to use language prior to learning science and (2) using language as a learning tool for science. Adapting different perspectives on language practices may result in distinct interventions and student outcomes. Additionally, the merits and barriers of using only talk or writing as learning tools to promote student learning in science are discussed to identify the rationale of the research questions in greater detail. Finally, to guide the data collection, analysis, and interpretation of results, the theoretical framework grounded in interactive constructivism is discussed.

Chapter Three provides the rationale for implementing the qualitative methodology that is used in the study by discussing the nature of argumentative practice and the patterns of the combination of talk and writing to support students' learning in science. In order to answer each research question specifically, two qualitative research approaches were purposefully employed: (1) generic qualitative and (2) multiple-case study. One class, consisting of twenty-two students, was selected using a purposeful sampling technique, because the teacher has incorporated an argument-based inquiry approach into his classroom at a high level of implementation for the past three years. To carry out methodological triangulation and reduce the subjectiveness of qualitative coding patterns and interpretations, three data analytical approaches were conducted: (1) the constant comparative method, (2) the enumerative approach, and (3) in-depth analysis of knowledge construction trajectory (KCT) episodes. Finally, to ensure the quality of this study, four dimensions and criteria of trustworthiness reframed by Lincoln and Guba (1985) are explained, which include credibility, transferability, dependability, and confirmability.

In Chapter Four, three main findings are identified: (1) students' increased understanding of the nature of argumentative components for public negotiations, (2) students' increased ability of crafting written arguments, and (3) five patterns of talk and writing for knowledge construction. First, students developed and used more argumentation components over time, such as information seeking, challenging, defending, rejecting, and supporting. Students came to focus on the relationship between claim and evidence as well as the quality of evidence in challenging others' arguments. Students also began to use evidence to defend, support, and reject each other's arguments in public negotiation processes over time. Second, students developed a high quality of written arguments over time. Those results indicated that talk and writing are interdependent in argumentative practices. Finally, five patterns of talk and writing were identified: (1) talk alone, (2) writing alone, (3) talk and writing were used in sequence, (4) talk and writing were used simultaneously, and (5) the combination of sequence and simultaneity. The findings suggest that when talk and writing were used in combination, student knowledge construction occurred more than when only one learning tool was used. In addition, when talk and writing were used in sequence or simultaneously, students' higher cognitive processes provided more scaffolding than when talk and writing were used alone. Importantly, while talk and writing used in sequence was more teacher-directed, talk and writing used simultaneously was more student-directed.

Finally, Chapter Five discusses the findings of this study in terms of six aspects: (1) understanding of argumentation, (2) ability of crafting written arguments, (3) use of talk and writing, (4) cognitive processes, (5) meaning of negotiation, and (6) methodology consideration. Additionally, theoretical and pedagogical contributions of this study are discussed. Finally, the limitations of the study and possible directions for future research are provided.

CHAPTER TWO

LITERATURE REVIEW

This chapter explores the role of argumentation in science, discusses different positions of language practice to support students' construction of science, reviews the merits and barriers of current research by using talk alone, writing alone, and talk and writing together, and develops a framework for studying argumentative practices. Further, this examination provides support for the use of the Scientific Writing Heuristic (SWH), an argument-based approach used by the teacher and students in this study. This chapter also explores what research reveals about the challenges and gaps regarding the argumentative practice in science classrooms.

Argumentation as a Core Practice for Scientific Literacy

Scientific literacy is seen as the desirable general outcome of learning science (American Association for the Advancement of Science, 1993; Hand, Yore, Jagger, & Prain, 2010; Howes, Lim, & Campos, 2009; Klein, 2006; Millar, 2006; Moje, 2007; Norris & Phillips, 2003; Sadler & Zeidle, 2009; Wallace, 2004). The use of inquiry approaches to improve students' scientific literacy has recently become a focus of research in science education (Fang, 2005; Prain, 2009). A primary goal of scientific inquiry is to engage students in the activities and thinking processes of scientists to develop a conceptual understanding of the natural world (Abd-El-Khalick et al., 2004; Akkus, Gunel, & Hand, 2007; Bilss, 2008; Chinn & Malhotra, 2002; Jiménez-Aleixandre & Erduran, 2008; Kuhn, Black, Keselman, & Kaplan, 2000; Ruiz-Primo et al., 2010; Sandoval, 2005). It is important to emphasize that scientific inquiry goes beyond executing experimental procedures, using instruments, recording data, and reproducing graphs to verify scientific knowledge in textbooks. It also involves argumentative processes that include constructing knowledge claims through interpreting data as sound evidence and debating those claims with peers. This emphasis on scientific inquiry reflects a distinct shift from the view of science as experiment verification to an understanding of science as argumentation and explanation (Bricker & Bell, 2008; Zembal-Saul, 2009). Consequentially, argumentation is a core practice of scientific literacy.

As Dusch and Osborne (2002) assert, “teaching science as a process of enquiry without the opportunity to engage in argumentation… is to fail to represent a core component of the nature of science or to establish a site for developing student understanding” (p. 41). In other words, students need to engage in the argumentative processes that scientists undertake when they construct valid knowledge in persuasive discourse. First, this involves a cyclic-cognitive process of making claims, marshaling evidence to substantiate the claims, and evaluating evidence to judge the validity of the claims (Choi et al., 2010; Kelly & Bazerman, 2003; McNeill, 2009; Peker & Wallace, 2009). A single individual can determine the validity of a claim by constructing a scientific argument as he/ she weighs evidence and considers relevant scientific theories to form a conclusion about a problem. Second, argumentation involves a social practice in which students make sense of the phenomena under study by proffering, evaluating, critiquing, challenging, and defending arguments through discourse (Berland & Reiser, 2011; Chin & Osborne, 2010). Driver et al. (2000) stress the importance of constructing arguments in this social aspect: “scientific understandings are constructed when individuals engage socially in talk and activities about shared problems or tasks. Making meaning is thus a dialogic process involving person-in-conversation” (p. 7). That is, argumentation can be seen as persuasion or the interactions that occur between individuals when they try to convince an audience of the validity of their knowledge claims.

Both cognitive and social processes are critical epistemic practices in science and afford avenues for the articulation of alternative viewpoints, cognitive dissonance, reflection, and reasoning, all of which can foster learning and the construction of knowledge (Sandoval & Millwood, 2005; Schwarz, 2009). This, in essence, is the belief underlying the view that engaging in argumentation is both a process of social interaction and a cognitive dynamic.

From this position, argument is viewed as being constructed through an individual cognitive process with its own meaning for each individual; however, it then becomes a process in which meaning is debated and discussed in interaction with others. The social process of negotiating an argument with others is a powerful vehicle for developing the higher-order thinking needed to advance individual conceptual understanding. In other words, social interaction offers a way to externalize the internal thinking strategies embedded in argumentation.

Not all researchers would agree with these two views/definitions of argumentation. For example, Eemeren and Grootendorst (2004) restrict the meaning of argumentation to its social aspects: "Argumentation is a verbal, social and rational activity aimed at convincing a reasonable critic of the acceptability of a standpoint by putting forward a constellation of proposition justifying or refuting the proposition expressed in the standpoint" (p. 1). They further construct a formal framework to define argumentation as knowledge justification and knowledge persuasion. Costello and Mitchell (1995) also highlight the social nature of this process and state that, "Argument, unlike formal logic, is a social operation, a particular mode of communication which is oriented to context and to purpose" (p. 1). Building on those positions, Berland and Reiser (2011) argue that "by its nature, scientific argumentation is a social practice" (p. 192). They view argumentation as a competitive process whereby students can strengthen their critique of other arguments.

However, Deanna Kuhn (1999, 2003), taking a cognitive development position, argues that argumentation is also collaborative and involves a specific cognitive process of knowledge construction. This cognitive collaborative process requires that students employ critical thinking skills to conceptualize, reason, and represent their mental models, logic, and ideas to others. Ford (2008) supports this position and claims that an argument can be constructed by a lone student and can also be *constructed* and *critiqued* in a social or dialogic process with other students. Jimenez-Aleixandre and Erduran (2009) further suggest that failure to integrate social and cognitive dimensions of argumentation in scientific inquiry may result in a failure to engage students in learning science. Thagard (1994), too, underscores the point that the cognitive and social dimensions of science are complementary and that definitions that focus on either purely cognitive or social interactions of science are inadequate. He states: "from a naturalistic perspective, we can appreciate science as a product of individual minds and as a product of complex social organizations" (p. 630). In this regard, the cognitive and social interactions of learning are mutually supportive of one another and intertwined such that "you cannot strip learning of its content, nor study it in a neutral context" (p. 271, Duschl, 2008).

Therefore, argumentation is defined in the current study as both an individual cognitive activity and a negotiated social act (Driver, Newton, & Osborne, 2000; Hand, 2008). Both the individual and social aspects of argumentation are essential for classroom practice, because they enhance students' ability to reason and justify claims as well as to interact with their teacher and peers in the process of constructing and critiquing their ideas. For this reason, a better understanding through both the cognitive and social processes of argumentation may result in the most effective learning of science.

However, incorporating both dimensions of argumentation, social interaction and cognitive dynamics, into classroom science is challenging for students (Duschl & Osborne, 2002). Sadler (2004) reviewed 13 articles to ascertain the difficulties of students' use of informal reasoning to understand socio-scientific issues in the context of argument. Three key conclusions were extracted from Sadler's study: (1) students do not commonly use scientific evidence to support their personal decision making, (2) students are not competent at analyzing and evaluating arguments, and (3) students often make unjustified claims and struggle to recognize opposing arguments. Similar to Sadler, Sampson and Clark (2009) reported that when students engage in scientific argumentation they struggle with generating a coherent explanation, using sufficient and appropriate data to shape evidence, and understanding what counts as good evidence.

Norton-Meier (2008) suggests that students could gain proficiency with argument and argumentation through *language practices* (Ford, 2008; Sandoval, 2005). Wallace and Narayan (2002) propose that, for students to construct knowledge in scientific inquiry where argumentation is a core component, they need to be involved in "learning to use language, think and act in ways that enable one to be identified as a member of the scientific literate community and participate in the activities of that community" (p. 4). Hand et al. (2010), reviewing major journals in science teaching from 1998-2008, further suggest language can be a powerful learning tool to link these two dimensions of argumentation as well as to better engage students in the practice of argumentation (Yore & Treagust, 2006). That is, language can be viewed as an argumentative process that occurs using different forms of language, engaging different representations of language, and working across different social settings.

Nonetheless, there has been an ongoing debate about the best approach to incorporate language within argumentative processes and practices, particularly in relation to science classrooms.

Language for Promoting Argumentation Practice

Language has been recognized as a critical component of doing science and constructing science understanding; language is also a means to communicate inquiries, procedures, and science to other people so that they can make informed decisions and take informed action (Keys, 1999; Lemke, 1990). However, there are at least two perspectives about the best approach to introducing language instruction within classrooms: (1) learning to use language prior to learning science and (2) using language as a learning tool for science.

Learning to Use Language Prior to Learning Science

The work of Halliday and Martin (1993) clearly emphasizes the need for students to engage with the structure of the genres of science as a precursor to doing science. They adopt the position that it is necessary to learn how to use language prior to learning the science. For instance, students are required to learn the structure of a laboratory report prior to engaging with laboratory activities. This opinion, to a certain degree, responds to Klein's (2006) view of first-generation cognitive science, in which language is a window onto thinking and learning. That is, language is viewed as a "by-product of thought, rather than a contributor to it [thought]" (p. 149). Language itself is not treated as a resource for constructing scientific knowledge.

Such perspectives were evident in two major research efforts: the IDEAS project (Erduran, Simon, & Osborne, 2004; Osborne, Erduran, & Simon, 2004; Simon, Erduran, & Osborne, 2006; von Aufschnaiter, Erduran, Osborne, & Simon, 2008) and the project conducted by McNeill and her colleagues (Berland & McNeill, 2010; McNeill, Lizotte, Krajcik, & Marx, 2006; McNeill, 2009; McNeill & Pimentel, 2010). In the IDEAS project, students were taught Toulmin's (1958) argument structure and then engaged in argumentative processes. Students were most often asked to generate explanations by evaluating evidence for competing mechanisms for a phenomenon. The findings revealed that students need to be "explicitly taught through suitable instruction, task structuring and modeling" (p. 996-997, Osborne et al., 2004). The research conducted by McNeill and her colleagues applied argument structures to students' construction of explanations by explicit instructions followed by prompts that faded in frequency as students gained experience in the development of explanations. These interventions explicitly emphasized the need to teach the structure of argument prior to doing science.

However, there were some problems with these studies. For example, Osborne et al. (2004) point out the limitations and difficulties of their approach. They state that their data did show evidence of positive improvement in the quality of student argumentation over nine months, but the change was not significant. They further state that argumentative skills are domain-specific and not easily transferable from one context to another context.

Schwarz (2009) argues that "the explicit teaching of argumentative skills is often valueless: since students acquire basic argumentative skills very early, what is more needed to contextualize these skills in educational settings" (p. 95). Cavagnetto (2010) supports this idea and further argues for this structure-oriented intervention in which "argument is more of a product of inquiry than an enmeshed component of inquiry" (p. 352). There is a need to create learning contexts where students are able to ask questions, revise what they know in the light of evidence, justify responses to classmates, analyze and interpret data, and use argument structure to learn science (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Norton-Meier, 2008).

Using Language as a Learning Tool for Science

Gee (2004) argues for the opposite position and claims that language should be embedded within the learning experience. In this position, language is viewed as a learning tool, and there is no separation between learning how to use language and learning science. This view can be explained by Klein's argument (2006) of second-generation cognitive science. Language becomes largely narrative and interacts with thoughts. Prain (2006) suggests that the using language as a learning tool position offers much more potential for learning gains than learning about language separately from the context of its use.

More recently, Hand (2008) suggests that there is a continuum of positions. While there is a requirement for students to engage with the language of the discipline as a learning tool, students also need to understand the structure of the genres used within science. Klein (2006), in discussing the relative importance of first- and second-generation cognitive science with respect to language practice, states that there is no one position that should be adopted. He suggests that in "the middle of the spectrum is practices that integrate expressive features of human thought and language with denotative features of authentic science text" (p. 171).

This study recognizes the need to have some middle ground that applies to the concept of scientific argumentative practice. Namely, language is not separate from science. There is a need to provide students with opportunities to be engaged with learning about science through using the language of science while they are doing science.

Translating this orientation of language practice to argumentative classrooms, learning scientific argument occurs through using scientific argument in investigative contexts (Clark & Sampson, 2008; Keys, Hand, Prain, & Collins, 1999; Martin & Hand, 2009; Sampson, Grooms, & Walker, 2011; Sandoval & Millwood, 2005; Sandoval & Reiser, 2004). Students need to be immersed in argumentative contexts to learn argument structure and construct scientific knowledge. For example, Sandoval and his colleagues provided the computer program ExplanationConstructor to support students to generate explanations in order to answer particular questions by linking evidence and claims. This became a tool to foster students in the construction of knowledge. They also designed activities in which groups critiqued each other's explanations, and self-assessed their own progress. This— an immersion-orientated process—creates cognitive conflict, reflection, and social interaction for students arguing to learn and learning to argue. In other words, the immersion-oriented approach involves students in cognitive processes and social interactions in which they construct scientific knowledge by using the argument structures.

To summarize, although most researchers agree upon the role of language in support of students' engagement in argumentative practices, they, to a certain degree, take different positions on the use of language practice for argumentation in science classrooms. The immersion orientation offers broad experience in the practice of scientific argumentation; however, the processes through which students develop a sophisticated understanding of argument structures and the nature of argumentation remain unclear. The pattern of argumentative practice also needs to be examined. In addition, although some scholars agree that students may easily transfer their understanding of argumentative skills to another context by using an immersion orientated approach, few studies have attempted to empirically test these ideas in the context of science. A final important issue involves what forms or types of language may best support students to learn science in classrooms in which argumentative practice is embedded.

Talk and Writing in Argumentation

The Effects of Talk in Argumentation

Many scholars strongly advocate the need to create environments where students can *talk* with each other as they construct arguments, explanations, models, and theories just as scientists argue with each other as they relate the evidence they select to their claims (Albe, 2008; Bennett et al., 2010; Chin & Osborne, 2010; Hogan, Nastasi, & Pressley, 2000; Maloney & Simon, 2006; Martin & Hand, 2009; McNeill & Pimentel, 2010; Scott, Mortimer, & Aguiar, 2006; Sherrod & Wilhelm, 2009). However, the discourse in the traditional science classroom has been dominated by teacher talk (Crawford, 2005). Frequently, classroom discussion follows an Initiate, Response, Evaluate (IRE) pattern (Macbeth, 2003; Mehan, 1979) in which the teacher normally takes the leader role by asking a question, a student responds to the question, and the teacher evaluates the student's response.

Lemke (1990) clearly suggests that "learning science means learning to talk science" (p. 1), and that this means moving away from science lessons dominated by teacher talk. He and other researchers (e.g. McNeill, 2009) argue that students become fluent speakers of science within peer group interactions and begin to make sense of their newly constructed ideas. This student-centered process is further supported by Ernest (1998), who contends that, for students, involvement in oral argument is a critical component in the development of epistemological knowledge of the discipline. He indicates that students use such discourse opportunities to both construct scientific knowledge claims and to participate in the dialectical process of criticism and warranting of peers' knowledge claims.

A recent study conducted by Martin and Hand (2009) reports that talk plays a critical role in supporting students' *ownership* of learning when engaging students in argumentative practices. They show that students take ownership of their learning via an increase in the amount of time that students' talk and subsequently an increase in the use of terminology such as claims and evidence. In a similar vein, Chinn and Osborne's study (2010) shows that students can drive the process of small group discussion themselves and can work independently of the teacher when they are provided opportunities to talk. These studies contend that students talk and collaborate with each other without constraints, where they can explore ideas without threats or being confronted prematurely with the authoritative explanation.

Moreover, the use of talk to enhance science learning has received theoretical support from many scholars (Bruner, 1986; Prawat, 1993; Vygotsky, 1962). For example, Britton (1982) theorized how understanding might be enhanced through talking:

> We come to an understanding in the course of communicating it. That is to say, we set out by offering an understanding and that understanding takes shape as we work on it to share it. And finally we may arrive co-operatively at a joint understanding as we talk or in some other way interact with someone else. (p. 115)

This view is supported by Chin and Osborne's (2008) study. They state that when students engage socially in talk activities about shared ideas or problems, students must be given ample opportunities for formulating their own ideas about science concepts, for inferring relationships between and among these concepts, and for combining them into an increasingly more complex network of theoretical propositions. For Hand (2008), the oral language component is heavily emphasized in the social negotiated processes in which students exchange, challenge, and debate arguments in order to reach a consensus.

However, Yore and Treagust (2006) argue that although talk is necessary for argumentation, it is "not sufficient to do and learn science" (p. 296). Recent research continuously reports that there are a number of barriers that students confront when merely using talk as a learning tool in argument-based classrooms.

Barriers of Only Using Talk in Argumentation

Several researchers have reported that students tend to process information on a surface level when they only use talk as a learning tool in the context of science education (Hogan, 1999; Kelly, Druker, & Chen, 1998; McNeill & Pimentel, 2010). For example, Kelly et al. (1998) applied Toulmin's argument framework to oral arguments about the function of electricity produced by pairs of students. Kelly and his colleagues found that students did not provide sound evidence for claims they made, although they usually challenged each other during discussions. Another study was conducted by McNeill and Pimentel (2010) in three urban 11th- and 12th-grade classrooms. After examining all classroom discussions without writing support, they concluded that persuasive interactions only occurred regularly in one teacher's classroom. In the other two classes, the students rarely responded to their peers by using their claims, evidence, and reasoning. Most of the time, students were simply seeking the correct answers to respond to teachers' or peers' questions.

Current research also suggests that students have a great deal of difficulty revising ideas through argumentative discourse (Berland & Reiser, 2011; D. Kuhn, Black, Keselman, & Kaplan, 2000). For example, Berland & Reiser (2011), emphasizing social practices of argumentation, examined two classes from sixth and seventh grade classrooms as they enacted an 8-week ecosystems unit. They reported that students struggled with revising their understanding in light of one another's ideas and evidence. They suggested the reason for this is that students may focus on the goal of persuading others, which is the nature of oral argumentation. This result is not surprising. Students usually engage in persuading other people of their ideas when they only use talk in the classroom, rather than reflecting on and revising their own ideas at that moment.

Students also have difficulty connecting everyday language and scientific language (Yore & Treagust, 2006). Prain (2007) argues that although student talk is valuable for engaging in argumentative processes, where students' everyday language is seen as an important resource for learning new science concepts and practice, the scientific and everyday language meanings of some words differ (e.g. weight, matter, and mass; force and energy). Hence, this causes problems in merely using talk for learning scientific concepts and vocabulary.

Given these potential barriers to only using, or too heavily relying on, talk as a learning tool in argumentative processes, researchers have tended to encourage students to also use writing as another learning tool to construct knowledge in argument-based classrooms. Yore and Treagust (2006) note that writing plays an important role "to document ownership of these claims, to reveal patterns of events and arguments, and to connect and position claims within canonical science" (p.296). That is, the writing undertaken as a critical role of the argumentative process requires students to build connections between the elements of the argument (question, claim, and evidence).

The Effect of Writing in Argumentation

There has been increasing debate over, to what extent, the act of writing can enable students to develop argumentative skills, learn about science, and demonstrate scientific understanding in a coherent way (Hand, Gunel, & Ulu, 2009; Kelly & Takao, 2002; Keys, 1999; McDermott & Hand, 2010; McNeill, Lizotte, Krajcik, & Marx, 2006; Sandoval & Millwood, 2005; Wallace, 2007). For example, Choi et al. (2010) found that the use of writing assisted students in generating meaning from data; making connections among procedures, data, evidence, and claims; and engaging in productive argumentation. In addition, Kelly, Chen, and Prothero (2000) found that writing helped postsecondary oceanography students establish a more thorough understanding of the argument structure. Along the same lines, Kelly and Takao

(2002) successfully used writing to support students in the construction of their own arguments.

The significance of using writing to assist students in the construction of scientific knowledge is also emphasized by Galbraith, Waes, and Torrance (2007), who state “writing is not just speech written down” (p. 3). They believe that “writing involves understanding the processes involved in producing and evaluating thoughts rather than the processes involved in translating thoughts into language” (p. 3). Namely, the function of writing is not just to translate what students think about the science topic into a written language for the teacher to read; it also serves to help students construct and evaluate their knowledge. This is similar to Emig’s (1977) notion that “writing serves learning uniquely because writing as process-and-product possesses a cluster of attributes that correspond uniquely to certain powerful learning strategies” (p. 122). Rivard (1994) also contends that writing plays an important role in fostering learning in science. When students write, they reflect on their thinking and come to a better understanding of what they know and what gaps remain in their scientific knowledge.

Yore and Treagust (2006) suggest that in completing a writing-to-learn task, students engage in three specific translation activities. First, they must translate the language of science into the language they typically use (home language) to comprehend the concept. Second, students must translate their understood meaning into the language of the audience to which they are writing. Students then typically need to translate back into science language when completing classroom assignments. Prain and Hand (2006) argue such translations require students to engage content knowledge, to frame writing upon rhetorical elements, and to consider written discourse patterns used by the audience to which they are writing. These translations help students clarify and reconstruct their scientific knowledge a great deal.

Recently, writing-to-learn research has been supported by psychological theories that propose mechanisms through which writing might promote students’ cognitive skills (Bereiter & Scardamalia, 1987; Galbraith, 1999; Hayes & Flower, 1980; Kellogg, 2008; Keys, 1999; Klein, 1999). McDermott and Hand (2010) have used a secondary reanalysis methodology to examine six studies they have conducted in argument-based classrooms over the past ten years. They found that students perceived cognitive action leading to benefits for their conceptual understanding when participating in the writing-to-learn tasks.

Nevertheless, recent researchers have continuously reported that there are some limitations to using writing alone to support student-constructed knowledge in argument-based classrooms.

Barriers of Only Using Writing in Argumentation

Current researchers have suggested that students have a great deal of difficulty developing a high quality of written arguments (Berland & McNeill, 2011; Sandoval & Millwood, 2005). For instance, Sandoval and Millwood (2005) examined students' understanding and quality of using data as evidence for specific claims through writing in four introductory high school biology classes. They found that students often failed to provide sufficient evidence for claims and to articulate how specific data related to particular claims. They further claim that engaging students in argumentative processes seems to create a sustained epistemic discourse context, in which students challenge each other's claims and evidence and thus consider in more depth what a particular representation really says and how that representation combines to produce converging evidence for or against particular explanations.

Similarly, McNeill (2009), in investigating the effect of embedding written argument structure in the classrooms, found that student learning performance on post-tests had been improved, but that they still had difficulty reasoning in their written arguments. She conjectures that students thinking and writing in terms of effective ways to justify claims are strongly influenced by social dialogue, which "offer[s] a way to externalize internal thinking strategies embedded in argumentation" (Jimenez-Aleixandre et al., 2008). This view is supported by Peker and Wallace (2010), who contend that peers' critique of students' written explanations helps them become immersed in the process of using argument to develop their conceptual understanding of reasoning skills and scientific explanations.

Recently, a study conducted by Berland and McNeill (2011) has explored the learning progression for argumentative processes. They found that students' written work typically lags behind their ability to communicate orally. They suggest that "students may have little reason to develop rich, convincing arguments in writing while a dialogic interaction provides students with that reason in the form of an audience to convince" (p. 25). Audience is important because it provides a purpose for their arguments. Without an audience to convince, students are often in the position to demonstrate that they understand the scientific concepts to their teacher but not to craft a convincing argument. However, few studies have examined how to foster students to develop an argumentative audience and better written arguments in argument-based classrooms. In other words, will simply combining talk and writing support students to develop better written arguments and ultimately construct scientific knowledge?

To summarize, research in the areas of oral argument and written argument consistently indicates that those two learning tools, used separately, may not be quite as useful as a strategy that combines them in order to obtain the benefits of both (Rivard & Straw, 2000). This view corresponds to Halliday and Martin's (1993) idea that talk and writing are highly interconnected. That is, a combination of talk and writing can promote students' argumentation and ultimately promote student conceptual growth. Under these conditions, it is assumed that students may be able to take advantage of the combination of talk and writing and as a consequence, the combination may result in better construction of scientific knowledge. How the combination contributes to student construction in science remains unclear.

Integrating Talk and Writing in Argumentation

Several researchers have lamented the fact that teachers rarely link these two learning tools in school instruction (e.g. Nystrand, Gamoran, & Carbonaro, 2001; Rivard, 2004). Moreover, few studies have been conducted to explore the interaction between talk and writing in science classrooms. So far, only two qualified quasi-experimental studies, conducted by Rivard and Straw (2000) and Rivard (2004), have reported interesting findings regarding the use of talk and writing in the science classroom.

Rivard and his colleagues have found that talk and writing together were more effective than either talk alone, writing alone, or a control condition in contributing to aggregate knowledge at a post-test and delayed post-test, especially of more complex concepts. They further report that talk is important for sharing, clarifying and distributing knowledge, whereas writing helps the development of more structured and coherent ideas. They suggest that science teachers should endeavor to include more writing tasks in the classroom after students have had sufficient opportunities for collaborative exploratory talk while being guided by cognitive engagement in argumentative processes.

Another interesting study conducted by Sampson, Grooms, and Walker (2011) consisted of examining nineteen tenth-grade students in six groups. They used students' written arguments as a pre- and post-test measure. They indicate that there seems to be a relationship between the way these students participated in scientific argumentation and the quality of the written arguments they crafted. Namely, groups that had higher levels of engagement in oral arguments also created higher quality written arguments. They suspect there seems to be a positive correlation between these two outcome measures. They further suggest that the development of the knowledge and abilities needed to engage in science oral argument and to craft written arguments, therefore, is an inherently social interaction as well as a conceptual and cognitive process. Nonetheless, there is no study that has explored in what way the combination of talk and writing contributes to students learning in science and their cognitive processes during knowledge construction.

Inquiry classrooms embedded with argumentative structures can be dynamic and more complicated than what than what the researcher of the current study expected. Students often collaborate with each other either in small groups or as a whole class. That is, written discourse and talking discourse are not separated; sometimes they occur simultaneously or amalgamate with each. A recent study conducted by Cavagnetto, Hand, & Norton-Meier (2009) found that students were engaged in talk associated with generating an argument for 25% of the time on average, but talk associated with representing an argument in a final written form accounted for 71% of the time (students were on task 98% of the time). Specifically, students oftentimes utilized talk and writing simultaneously to generate or defend their knowledge claims and interpretation of evidence. They further suggest that the kind of talk associated with writing occurring within the group context may have encouraged students to higher levels of argument than would have been achieved if the task had not required representation of the argument in written form. Such talk associated with writing generating an argument is different from talk alone or individual writing. To date, little consideration has been given to how writing and talk are combined by students in the process of constructing arguments consisting of claims, evidence, rebuttals, and warrants. Those considerations need to be examined empirically.

Intervention for Scientific Argumentation

Three types of orientations for scientific argumentation are recognized by Cavagnetto's (2010) review of interventions: (1) learning to use the structure of argument prior to learning science, (2) using argument as a learning tool for science (immersion), and (3) experiencing the interaction between science and society to learn scientific argument (socio-scientific issues). While the first two interventions emphasize a knowledge-constituting process through problem-solving activities[3], the third intervention has focused on learning argument through the use of socio-scientific issues.

Socio-scientific issues have been infused into science classrooms by many educational researchers to promote students' reasoning and argumentation skills via providing students with social dilemmas with concepts or technologies associated with science (Sadler, 2004; Sadler & Zeidle, 2009; Wu & Tsai, 2010; Yang, 2004). Nevertheless, as Osborne, Simon, and Erduran (2004) point out, "just giving students scientific or controversial socio-scientific issues to discuss is not sufficient to ensure the practice of valid argument" (p. 997). In the context of socio-scientific issues, students can draw on ideas and knowledge developed informally through their life experience and their ethical values. However, argument in an inquiry context requires students to coordinate data, claim, and evidence to generate valid knowledge and revise it. Cavagnetto et al. (2009) argue that "in most cases it [socio-scientific issue] neglects the material aspect of science" (p. 432). New knowledge may not be formed during the interventions of socio-scientific issues.

Some researchers question the usefulness of socio-scientific argumentation, suggesting that students may revert to making moral judgments rather than developing subject or content knowledge. For example, According to Sadler and Donnelly (2006), students rarely use content knowledge during argumentation, instead relying on their moral judgment.

The present study acknowledges the value of using socio-scientific issues as intervention for argumentation. However, given the logic from literature and the goal of the research question attempting to understanding the process of knowledge construction, rather than using socio-scientific issues to learn argument or learning argument separate from the investigation, for this study it may be more appropriate to utilize argument as a vehicle to learn science.

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[3] The current study discussed the first two positions of the interventions in terms of the role of language practice in the beginning of Chapter Two.

The Science Writing Heuristic (SWH) Approach

The science writing heuristic (SWH) approach is a pedagogical approach that provides science students with inquiry activities embedded with an argument structure that parallels scientists' reasoning and writing (Hand, 2008; Keys et al., 1999). The SWH approach was designed to embed argument within student explorations of natural phenomena. That is, argument was not considered something that was done to conclude the inquiry but was instead found throughout the inquiry as students generated questions, explored experiments, interpreted data, as well as constructed and critiqued claims based upon evidence.

From a practical standpoint, the SWH approach is a series of scaffolds that encourage students to use different forms of language in various settings as they engage in scientific inquiry and leads them to the generation and defense of a science argument. The SWH consists of two templates: a teacher template and a student template (see Figure 2.1). The approach focuses on negotiation processes embedding with argument structure. Rather than seeing science argument as something that is learned separately from doing science, students using the SWH approach are required to deal with the structure of argument to make sense of data and build their understanding of science. Argument in the SWH approach thus serves as a vehicle through which to learn science through negotiated activities.

Teacher Template

1. Exploration of pre-instruction understanding through individual or group concept mapping
2. Pre-laboratory activities, including informal writing, making observations, brainstorming, and posing questions
3. Participation in laboratory activity
4. Negotiation phase I-writing personal meanings for laboratory activity (For example, writing journals)
5. Negotiation phase II-sharing and comparing data interpretations in small groups (for example, making a group chart)
6. Negotiation phase III-comparing science ideas to textbooks or other printed resources (For example, writing group notes in response to focus questions)
7. Negotiation phase IV-individual reflection and writing (For example, writing a report or textbook explanation)
8. Exploration of post instruction understanding through concept mapping

Student Template
1. Beginning Ideas—What are my questions?
2. Test—What did I do?
3. Observation—What did I see?
4. Claim—What can I claim?
5. Evidence—How do I know? Why am I making these claims?
6. Reading—How do my ideas compare with other ideas?
7. Reflection—How have my ideas changed?

Figure 2.1 The Science Writing Heuristic Teacher Template and Student Template

In addition, the SWH emphasizes integrating talk and writing to support students' learning in science and to improve their cognitive actions and social interaction. Students are required to complete a write-up of the investigation after they have had the opportunity to have their claims and evidence debated by their peers. Hand (2008) summarized the characteristics of SWH as follows:

> The SWH approach places emphasis on two key language experiences as critical components of the approach. These are the oral language experience and writing-to-learn experiences that are interwoven as integral components to the whole process. (p. 199)

Previous research on the SWH approach indicated its efficacy for promoting student conceptual understanding (Keys et al., 1999), cognitive engagement (Grimberg & Hand, 2009), and understanding of science questions, claims, and evidence (Hand, Wallace, & Prain, 2004; Martin & Hand, 2009). As such, this study utilized the SWH approach to provide students an argument-based environment in which to explore their research questions, collect data from investigations, generate evidence in support of their claims, present the argument in order to revise it, and construct scientific knowledge.

Theoretical Framework of the Study

Interactive Constructivism

While most contemporary scholars support a constructivist view of learning in general, there has been debate over the particular types of constructivist activities in learning. This study employed interactive constructivism as a theoretical framework which premises that learning has both a public and private landscape (Driver, 1996; Henriques, 1997). The public landscape of learning suggests that students construct knowledge and learn when they are able to interact with the physical world and other people. In contrast, private learning occurs when students reflect on and make sense of their interaction. Henriques (1997) states the view of learning held by interactive constructivists: “Only when students have time for both the public and private aspects of learning are they able to reconcile their previous ideas with their new experience” (p. 5). In fact, interactive constructivism merges aspects and tenants of radical constructivism (von Glasersfeld, 1989), social constructivism (Vygotsky, 1978), and information processing (Mayer, 1996; Zahorik, 1995) into its theory of learning.

Radical constructivism emphasizes that knowledge is created rather than discovered by individuals in an historical and cultural context. Knowledge refers to individual experience rather than the world. Each student’s particular understanding of a phenomenon is considered equally valid. Therefore, in a radical constructivist classroom, knowledge is most likely viewed as relativistic (Prawatt, 1999). Each individual’s own understanding must be considered valuable. However, from a pragmatic viewpoint, this would make any assessment of student understanding problematic as most ideas and perspectives students posit would necessarily be judged appropriate.

Social constructivism is the theory that knowledge is constructed through individual interactions within a social cultural environment. The ideas held by the group are considered valid as long as consensus exists (McCarthey & Raphael, 1992). Learning occurs when there is internalization of ideas between individuals. This position is typically traced to Vygotsky's (1978) ideas promoting the initiation of all higher human functions arising from social interactions. However, in emphasizing the consensus constructing scientific knowledge, the social constructivist position neglects the importance of individual scientists engaging in independent thought to move science understanding forward. In the science classroom, this view of learning discourages the creative aspect of the nature of science.

As students learn and encounter new phenomena, they are involved in a continuous process of creating a "goodness of fit" between the new stimuli and their previous understanding of the world. This is called information processing. It is important to note that the students' ultimate goal in school science is the same understanding of the subject matter as the experts in the field.

Building on interactive constructivism, I view learning in science classrooms as a series of active negotiations of meaning in or between the private aspects (radical constructivism) and the public aspects (social constructivism) of knowledge development to achieve a learning goal (information processing). This view of learning is supported by the National Science Education Standards, which state that "student understanding is actively constructed through individual and social processes" (p. 28). Along this line, many scholars suggest that language use is central to the learning process in both its public and private aspects (Kelly & Chen, 1999; Lemke, 1990; Scott, Mortimer, & Aguiar, 2006; Yore & Treagust, 2006). The following section discusses why language is important for science learning and defines the meaning of language for this study.

Language as a Learning Tool

Learning in science can be viewed as a process of negotiating meaning that uses different forms of language (e.g. oral and writing), different representations of language (e.g. notes, reports, tables, graphs, drawings, diagrams), and occurrs within different social settings in private and in public (Hand, 2008). Scientists use oral and written descriptions of events, predictions of future events, speculations of causality, formulations of interrelationship, and metaphoric models to help conceptualize science for themselves and their peers. Language thus plays a critical role in science. If we remove language forms from science, science cannot exist (Florence & Yore, 2004; Hand, 2008; Norris & Phillips, 2003). That is, there is no science without language. Language, in this study, is therefore more than just text. Rather, language is defined as a learning tool that includes different forms and different representations.

Recognition of this relationship between language and science is emphasized by some reformed documents (American Association for the Advancement for Science [AAAS], 1993; NRC, 1996, 2007) which focus on the ability to use language to build understanding of science concepts, to engage intelligently in public discourse and debate, and to construct explanations of natural phenomena in many different ways and communicate ideas to others. This emphasis on language and science requires teachers to create situations in which students can use language for either communicative purposes or constructing new knowledge to learn science (Zembal-Saul, 2009). Scientific discourse is thus characterized by the use of special patterns of language which enable students to identify and ask empirical questions, describe ideas about prediction, claims, and supported theory, critique an idea, and specify types of critiques. In summary, language is a learning tool for science.

Given this emerging perspective on language and learning science, language shapes and influences individual thoughts and knowledge construction. This perspective is supported by various researchers working in the writing-to-learn field (McDermott & Hand, 2010). These researchers argue that students should be encouraged to use different writing tasks or reflection to make tacit ideas explicit, to strengthen the connections between concepts, and to change conceptions. This is an individual negotiating process through language.

In addition, language is used not only at the individual level, but also at the social level through listening to ideas, questioning ideas, and defending ideas. Through this lens, learning in science is a process of negotiating meaning among individuals using various forms of language. Figure 2.1 summarizes the conceptual framework that guided this study.

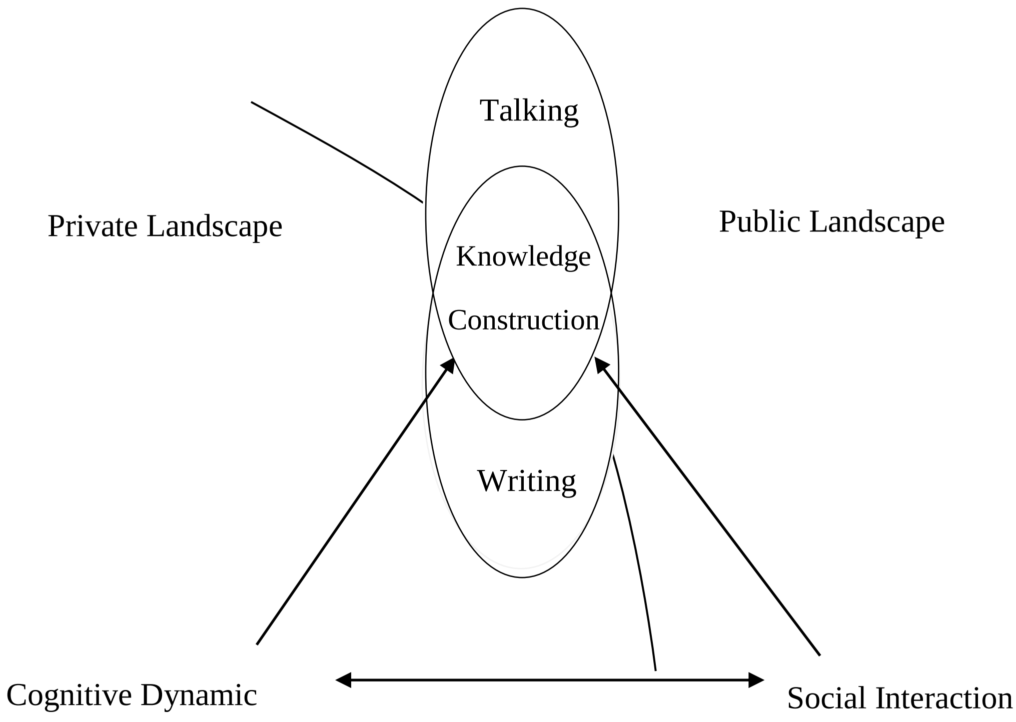

Figure 2.2 Conceptual Framework for this Study

The framework in Figure 2.1 represents the major premise that students construct knowledge in both public and private landscapes. Knowledge construction in the public landscape involves the process of social interaction in a cooperative learning environment that impacts student cognition. Knowledge construction in the private landscape involves the process of individual cognitive dynamic through reflection, interpretation, and meaning making. In this framework, when students move quickly and effectively between the two landscapes, their knowledge construction can best be facilitated. What makes their moves successful for knowledge construction is the use of language (Ford & Forman, 2006). Stated differently, knowledge construction involves an iterate process of negotiating meaning between a cognitive dynamic in individuals and social interaction in small group and whole class settings while utilizing a variety of language forms and modes for representing those meanings. Although other forms of language are used to construct knowledge, talk and writing have been considered as two critical and powerful learning tools of knowledge construction in science classrooms by a number of scholars (Galbraith, Wase, & Torrance, 2007; Rivard, 2004; Yore & Treagust, 2006). This framework serves as a conceptual model for data collection, analysis, and interpretation in this study.

Argumentation and the Structure of Argument

Although educational researchers agree upon the important role of argument and argumentation for knowledge construction in science, there exist, to a certain degree, different definitions of argumentation and the argument structure supported by different researchers due to their knowledge background and beliefs (Driver et al., 2000; Kuhn, 1993; McNeill et al., 2006; Osborne & Patterson, 2011). For example, McNeill and her colleagues (Berland & McNeill, 2010; McNeill & Krajcik, 2008; McNeill et al., 2006; McNeill, 2009; McNeill & Pimentel, 2010) describe scientific argument as synonymous with scientific explanation. They posit that “explanations often refer to how or why something happens” and explanation includes three components: claim (a conclusion about a problem), evidence (data that support the claim), and reasoning (a justification, built from scientific principles, for why the evidence supports the claim) (p. 157, McNeill et al., 2006). They do so to align their work with science standards (AAAS, 1993; NRC, 1996) that their teachers need to address their goal “to help students construct scientific explanations about phenomena in which they justify their claims using appropriate evidence and scientific principles” (p. 155, McNeill et al., 2006). Along the same lines, Ruiz-Primo et al. (2010) contend that “explanations are answers to particular questions” and “should connect patterns of data with claims about what the data mean” (p. 586).

However, Osborne and Patterson (2011) argue that “these [claim, evidence and justifications] are the elements of an argument rather than an explanation and that such definitions misconstrue the nature of explanation" (p. 630). Drawing on Toulmin's work (1958), they further underscore that explanation and argument have different goals: "whereas the goal of scientific explanation is to provide a causal account of events in the material world, argument seeks to use data and warrants to justify belief" (p. 633). Having different goals, the two linguistic structures have different criteria for their evaluation.

To guide the work of this study, I adopted a view of argumentation in science as a *process* of knowledge construction in which individuals clarify, critique, construct, and revise ideas in an effort to make sense of the nature of world (Driver et al., 2000; Hand, 2008; Sampson & Clark, 2008). This perspective also differentiates between terms such as *explanation* and *argument*. Explanation is a statement that "describe[s] nature phenomenon" (p. 456, Sampson & Clark, 2009) and seeks to make plain and generate that sense of increased understanding (Osborne & Patterson, 2011). Argument is a *product* that seeks to justify an explanation or to persuade (Osborne & Patterson, 2011).

To guide data analysis and interpretation, this study modified Sampson & Clark's (2008) model[4] and identifies the structure of scientific argument consisting of three interrelated components: question, claim, and evidence (Norton-Meier et al., 2008) (see Figure 2.3).

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[4] Sampson & Clark's (2008) original model consists of three components: explanation (similar to Toulmin's claim), evidence (similar to Toulmin's data), and reasoning (a combination of Toulmin's warrants and backings).

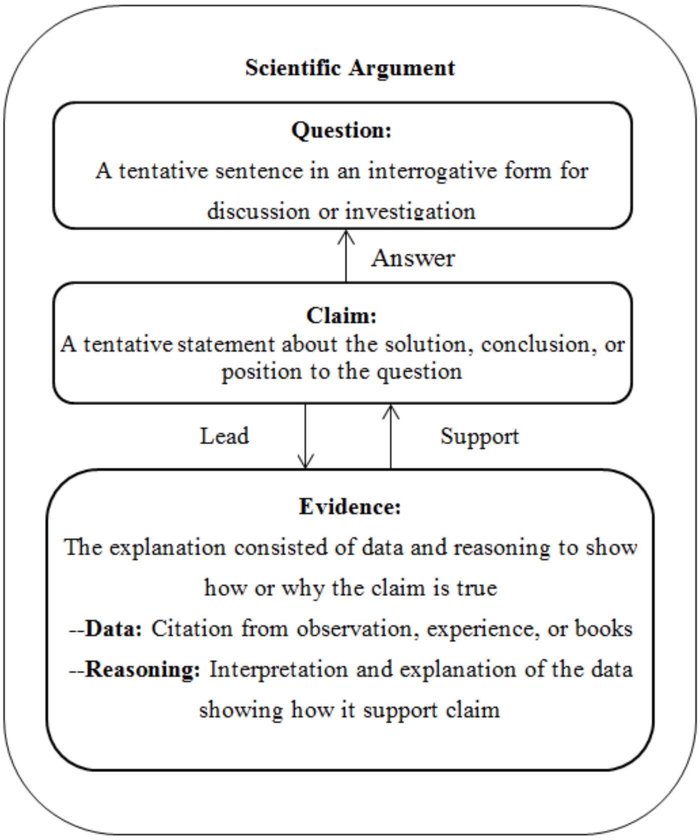


Figure 2.3 The Argument Structure Framework Used in the Study

Question

In understanding natural phenomena, identifying the research question is the first step of the process of argument-based inquiry. As Dewey (1938) said, without a question, there is just the blind groping in the dark. That is, the purpose of a question is to guide the students' investigation and discussion. Questions are recognized as such if the student meets an uncertainty or feels a difficulty needing to be solved. Further, once a question has been identified, students pursue a solution by surveying related information, formulating assumptions, interacting with the question and observing the results. In this regard, a question is a sentence in an interrogative form for the first step of processing a discussion or conducting an investigation.

Claim

A scientific knowledge claim includes the solution, conclusion and position about observations and discussion to answer the question. The claim is a tentative statement that one knows not only what a phenomenon is, but also how it relates to other events, why it is important and how this particular view of the phenomenon came to be (Driver et al., 2000). With this in mind, a claim is not just a statement of one's opinions, but the claim must also answer the question and be supported by and fit the evidence.

Making a high quality scientific claim is not easy for students (Norton-Meier et al., 2008; Jeong, Songer, & Lee, 2007). Prain and Hand (1999) investigated students' perceptions of science, science writing, and learning and found that students were not able to explain how knowledge claims are constructed. Students usually focus on the correctness of the claim, rather than looking at the relationship among question, claim, and evidence (Choi et al., 2010; Takao & Kelly, 2003). Students may draw on personal views or beliefs to explain phenomena and generate a claim, rather than use the data at hand (Chinn & Brewer, 1993). Whether students provide a high quality of knowledge claims from observation or discussion may depend on students' understanding of what counts as a claim and their critical thinking skills to seek out the patterns of data.

Evidence

Evidence in its broadest sense includes anything that is used to determine or demonstrate the truth of a claim (Sandoval & Millwood, 2005). Evidence is accumulated through observations of phenomena that occur in the natural world or that are created as experiments in a laboratory or in reading materials. Essentially, evidence is the explanation consisting of *data* and *reasoning* to show how or why the claim is true. A high quality of scientific evidence is need to sufficiently and appropriately support the claim to make it valid (Bell & Linn, 2000; Jeong et al., 2007; McNeill et al., 2006; Peker & Wallace, 2009; Sandoval, 2003). *Sufficient,* in this context, means to provide enough data to support and determine the claim. Providing sufficient evidence requires using multiple pieces of data and reasoning. *Appropriate* signifies data and reasoning that are relevant to determine, support and make the claim.

For Hand (2008), evidence does not equal data. Data without reasoning cannot *speak* to or *support* the claim. Hence, evidence includes data and reasoning. Data can be presented in many forms of language, such as graphs, diagrams, and pictures, to extract regular patterns by individual students. Reasoning is the logical explanation for why the data extracted by students supports the claim. Different students looking at the same raw data may generate different evidence due to their view of extracting the data from raw data and reasoning for the extracted data.

In sum, this study identifies the definition of explanation, argumentation, and the structure of argument. The framework of the argument structure is created to help the research for data analysis and interpretation in this study.

Summary

This chapter presented the existing research problems of argumentative practices and the theoretical framework in which this study is grounded. To engage students in argument-based inquiry, both cognitive dynamic and social interaction need to be considered. Incorporating both perspectives in science classrooms is difficult. Talk and writing have been offered as critical language tools for promoting student argumentation and ultimately advancing knowledge construction in science. However, argumentative practice does not occur in the short-term. To date, little research has investigated how students develop their understanding of the nature of argumentation when they engage in negotiated activities over time. To learn how to better support students to engage and develop their understanding of the nature of argumentation, identifying the core components of argumentation that students use for negotiation is needed. In addition, given the scarcity of research exploring the combination of talk and writing, this study attempted to understand how the combination contributes to students' learning in science. Finally, to guide data collection, data analysis, and interpretation, this study adopted interactive constructivism as its framework as well as defined the meaning of argument, explanation, and the structure of argument.

CHAPTER THREE

METHODOLOGY

The purpose of this chapter is to establish the methodological framework for the study as well as to identify data collection, data analysis procedures, and trustworthiness. This chapter will begin with a discussion of the rationale for the use of a qualitative approach to examine the potential of using talk and writing as learning tools to support students' understanding of the nature of argumentation and construction of scientific knowledge in two units over sixteen weeks. Next, the context of the study and the participant sample are described. Detailed accounts of data collection and analysis procedures are discussed. Finally, four criteria for assessing the trustworthiness of the findings reframed by Lincoln and Guba (1985) are reviewed: credibility, transferability, dependability, and confirmability.

Research Design

This study focused on two research questions: (1) How do students develop an understanding of the components of argumentation for public negotiations over time when participating in an argument-based inquiry classroom? (2) In what ways do talk and writing support scientific knowledge construction in an argument-based inquiry classroom? To answer each research question specifically, two qualitative research approaches were purposefully employed: (1) Generic qualitative approach and (2) Multiple-case study approach.

The generic qualitative approach (Merriam, 1998) was conducted to answer the first research question. This approach does not extend to "building a substantive theory as it does in grounded theory studies," but it does result in "the identification of recurring patterns that cut through the data or in the delineation of a process" (p. 11, Merriam, 1998). In this regard, the generic qualitative research design is appropriate for identifying common patterns in the development process of students' understanding of the nature of argumentation via talk and writing in public negotiated activities in an argument-based inquiry classroom over sixteen weeks. The generic qualitative approach provided several advantages given the research question and goal. First, it allowed for the extraction of regularities in the argumentative process from a group of students rather than focusing on a specific case. Second, it allowed for the examination of changes in the ways that students interacted with ideas, materials, and each other in greater detail than is often feasible in quantitative studies with large samples. Finally, and most importantly for the research on argumentative practice, it aided an examination of how a group of students develop their understanding of the nature of argumentation for talk and writing over time.

The second research question focused on how talk and writing support students' scientific knowledge construction in an argument-based inquiry classroom. A multiple-case study design was used to answer that research question. While many case studies focus on a single case because of its unique characteristics or research purpose, the multiple-case study design allows researchers to search for similar patterns or regularities across multiple single cases in depth. Using this approach, this study aimed to identify common patterns in the process by which individual students constructed their knowledge using a combination of talk and writing in the context of argument-based inquiry over sixteen weeks.

Three students were selected for in-depth study of their learning trajectories in an argument-based classroom. Each of the three participating students was considered a single case in the study that constituted this multiple case study. In other words, each case was "specific, a complex functioning thing" (Stake, 1995, p. 2) that served as a conduit to understand the relation between the integration of talk and writing and knowledge construction. Due to the complexity of the students' understanding of argumentation and scientific concepts, multiple data sources and analytical approaches were used.

Context

School

The study was conducted in a fifth grade science classroom taught by one white male teacher at a rural elementary school in the Midwestern United States. This school is an intermediate school for grades four through six. During the 2010-2011 academic year, the school district served around 510 students with approximately 21% of students qualifying for free and reduced lunch and 15% of students identifying as eligible for Individual Education Programs (IEP). The ethnic diversity of the student population at the school was 93% White, 4% Asian American, 1.5% African American, and 1.5% Hispanic American.

Teacher and Instruction

The teacher participating in the study had 10 years of teaching experience at the time of the study, 3 years in special education and 7 years in fifth grade. He had been involved in a professional development workshop for using an argument-based inquiry approach—the SWH approach—to promoting students' learning in elementary science classrooms for the past three years (2007-2010). The workshop aided teachers in designing instructional units around big ideas and provided opportunities for them to align learning theory with pedagogical practice. This teacher was selected using a purposeful sampling technique because he had incorporated the argument-based inquiry approach in his classroom at a high level of implementation. In the summer of 2010, he was recruited as an instructor for a SWH professional development project to guide participating teachers in the implementation of the argument-based inquiry approach in science classrooms.

As part of previous research on the SWH approach, several videotaped observations of this instructor's teaching over the past three years were randomly selected and scored using the modified Reformed Teaching Observation Protocol (RTOP) (Sawada et al., 2002). The RTOP scoring rubric was designed as a quantitative way to measure teachers' progression toward instructional practices identified by the National Science Education Standards (i.e., standard-based, inquiry-based and student-centered) (NRC, 1996). The protocol utilizes a Likert-type scale with a range from zero (the characteristic never occurs in the class) to four (the characteristic is very descriptive of the class). Table 3.1 shows the average RTOP score of the teacher's classes for the past three years. As shown in Table 3.1, the teacher's total RTOP score has been high since 2008. The RTOP subscales for teacher questioning, teacher role, student voice, and science argument were also aligned with reformed teaching in 2008 and 2009.

Previous studies of the SWH approach indicated that a teacher's level of SWH implementation is positively related to the teacher's RTOP score (Cavagnetto, Hand, Norton-Meier, 2010; Martin & Hand, 2009). The SWH approach places emphasis on integrating oral language and writing-to-learn activities to support students in learning science. In addition, this approach attempts to have students use science arguments in classrooms to construct, debate, and negotiate their ideas with other students and the teacher. The SWH approach can be identified as having five phases: 1) beginning ideas/ inquiry question, 2) test/ observation, 3) claim/ evidence, 4) reading, and 5) reflection, as shown in Table 3.2. In each phase, teachers are encouraged to use talk and writing as learning tools to support students' engagement in argumentative practice.

Hence, the teacher, with a high level implementation of the SWH approach for the past three years, was expected to utilize oral language and writing-to-learn activities to promote students' argumentative practice in his teaching in a coherent way. In this regard, the researcher in this study expected to see a range of strategies combined with talk and writing as learning tools to promote students' argumentative practice and understanding of the nature of argumentation occurring in the teacher's classroom.

Table 3.1 The Average RTOP Score and Description of the Teacher's Classes from 2007 Fall to 2010 Spring

Academic Year	**2007 Fall-2008 Spring**	**2008 Fall-2009 Spring**	**2009 Fall-2010 Spring**
Level of Implementation	**Medium (33/52)**	**High (40/52)**	**High (45/52)**
Teacher Questioning	--Teacher's questions encouraged students to display their ideas by actively listening to what students are saying	--Teacher's questions moderated and clarified students' ideas by comparing different voices	--Teacher's questions triggered divergent modes of thinking by framing problems or framing phenomena that can have more than one valid interpretation
Teacher Role	--Teacher was patient with students and acted as a resource person	--Teacher's support was carefully crafted to the idiosyncrasies of student thinking	--Teacher was often found helping students use what they know to construct further scientific understanding
Student Voice	--Students actively communicated with each other	--Students were involved in the communication of their ideas to others using a variety of means	--Students were involved in the communication of theirs ideas to others using a variety of means, and developed critical portions of the lesson through discourse
Science Argument	--Teacher demanded connections between questions, claims, evidence, and reflection	--Teacher encouraged a variety of ideas to be presented and challenged	--Teacher promoted linkage to big ideas, claims, and evidence as well as promoted debate and reasoning on these ideas supported by evidence

Table 3.2 General Phase of SWH Approach to Inquiry by Using Talk and Writing

Activity / Learning Tools	**Beginning Ideas/ Inquiry Question**	**Test/ Observation**	**Claim/ Evidence**	**Reading**	**Reflection**
Talk	--Teacher attempts to determine students' current knowledge --Question identified for investigation	--Students discuss how to conduct an experiment	--Students discuss their claims and evidence in a small group --Students present and debate their group claims and evidence in a whole class setting	--Students discuss the information they get from experts	--Students discuss the whole process to see which of their ideas changed compared with their beginning ideas
Writing	--Students write down their ideas about the current unit and inquiry questions	--Students record the data from their observations	--Students write up the group's claim and evidence in a small group --Students write up claims and evidence individually	--Students write down and compare their ideas with experts	--Students write up how many of their ideas changed during the course of the inquiry

Participants

Twenty-two students were in the class (10 females, 12 males; 1 Asian American, 21 Whites; 2 IEP students). These students had moved from a class using traditional lecture methods and had little experience with using argument structures to coordinate data, claims, and evidence as well as to debate ideas with peers. Therefore, this situation provided the researcher with an opportunity to answer the first question about how they developed their understanding of the nature of argumentation through public negotiations over time.

To understand students' perceptions, reasons, and thinking about their actions and talking in the classroom, six students were selected as target students to be examined in depth. Based on current literature on science learning, gender (Burkam, Lee, & Smerdon, 1997; Rivard, 2004), past science achievement level (Klein, 1999; Rivard, 2004), and level of verbal participation in the whole class and small group discussions (Hogan, Nastasi, & Pressley, 2000) appear to be important mediating variables that determine the effectiveness of talk and writing for learning science; thus, the six students were purposefully selected considering distribution of gender, past science achievement levels, and level of verbal participation in class discussions. The intent of using a purposeful sampling was not to look for differences in the use of language-based strategies to construct scientific knowledge between genders, science achievement levels and level of verbal participation in class discussions. Rather, this study attempted to identify similar patterns or regulations across the selected samples. However, this study recognizes that these classifications were only a representative sample because students act and achieve differently in different task contexts within the same classroom (Hogan, Nastasi, & Pressley, 2000).

Six students (two girls, four boys; three high achievements, three medium achievements; three initially talkative students, three initially quiet students) were selected as target students from 22 students to represent the diversity within the classroom, as shown in Table 3.3. Selection of students was based on documentation of students' past achievement in science, teacher recommendation, researcher's observations of students for three weeks, and students' willingness to participate in the study. To determine the level of verbal participation in class discussions, the researcher randomly chose two classes engaged in whole-class discussions from the first three weeks of the semester and counted the frequency of their utterances. The average frequency of utterance for each student in the two selected classes was five times in an hour. If the frequency of a student's utterance was higher than average, the student was categorized in the talkative group. In contrast, if the frequency was lower than average, the student was categorized in the quiet group. The frequency of the six target students' utterances in an hour is shown is Table 3.4.

Table 3.3 Information about Target Students

Student	**Gender**		**Science Achievement Level**		**Verbal Participation Level**	
	Female	**Male**	**High**	**Medium**	**Talkative**	**Quiet**
Olivia	✓		✓		✓	
*Blair	✓			✓		✓
*Kurt		✓	✓		✓	
*Nolan		✓		✓	✓	
Mike		✓		✓		✓
Ryan		✓		✓		✓

*Indicates that the student was selected to participate in the second research question.

Table 3.4 Information about Target Students in the Talking Frequency of Utterance per Hour

Student	**Frequency of Utterance per Hour**	**Verbal Participation Level**
Olivia	12	Talkative
*Blair	3	Quiet
*Kurt	8	Talkative
*Nolan	6	Talkative
Mike	2	Quiet
Ryan	0	Quiet

*Indicates that the student was selected to participate in the second research question.

Due to the dynamic and complex nature of argument-based inquiry classrooms, students usually investigated phenomena in small groups consisting of 2-4 students. In addition, the teacher sometimes allowed students to choose their partners for their group investigations and consequently the six target students had different partners at different times. Because of this arrangement, students interacted with different peers in different contexts. The advantage of this situation, without controlling the teaching environment and classroom dynamics, was being able to understand the nature of the argument-based inquiry classroom and the interaction among students who could debate their ideas with different peers in different contexts. This situation provided a useful opportunity to capture similar patterns emerging from a variety of students and interactions. However, this situation also made data collection difficult. The disadvantage was that it was not possible, to a large extent, to videotape six students in different groups at the same time, because that video-camera setting might greatly influence student learning. Due to these reasons and attempts to address the second research question, three students (Blair, Kurt, and Nolan) were then selected from the six target students for careful observation when they were discussing, investigating, and writing in small groups. Their selection was based upon the criteria of gender, science achievement, and level of verbal participation in class discussions.

Two Units—Ecosystem & Human Body System

The data in this study were collected from two units over sixteen weeks. The first unit was ecosystem, consisting of two subunits: plant investigation and population fluctuations. The second unit was human body system, mainly focusing on the digestive, respiratory, and muscular systems. The teacher implemented the SWH approach to help students construct knowledge for the two units.

For each unit, the teacher provided a big idea for students based upon the Iowa Core Curriculum for Science, National Science Education Standard (NRC, 1996), and Benchmarks for Science Literacy (AAAS, 1993), as shown in Table 3.5. All classroom activities, discussions, and investigation questions were related to the big idea for each unit. For example, the big idea of the first unit was “Living things and their environment affect each other.” Students were asked to generate investigation questions for the subunit on plant investigation. For example, some students came up with questions like “How many kinds of animals are there in the world?” This research question was critiqued and rejected by other students due to the appropriateness of the relationship between the research question and the big idea. Finally, students generated the final investigation question, which was, “What do seeds/plants need to live?" After students generated the investigation question, they were asked to design the investigation to collect data, develop their claim and evidence, and propose their group argument in a whole class setting for negotiations. The negotiated process is essential for the argument-based inquiry approach—the SWH—which helps students to develop, revise, and reconstruct their knowledge via debating with their peers and teachers. Finally, students were expected to build the core concepts, as shown in Tables 3.5 and 3.6.

The core concepts of each unit were based upon the teacher's lesson plans, Iowa Core Curriculum for Science, National Science Education Standard (NRC, 1996), and Benchmarks for Science Literacy (AAAS, 1993). Tables 3.5 and 3.6 are descriptions of the essential question, overarching idea, and core concepts of the two units that students covered during this study—ecosystems and human body.

Table 3.5 Essential Question, Big Idea, and Core Concepts of Ecosystem Unit

Essential Question	How do various factors affect environmental balance?
Big Idea	Living things and their environment affect each other
Core Concepts	1. A seed needs water, air, and correct temperature to germinate 2. Living systems require continuous energy input 3. Energy transforms from producers through levels of consumers and decomposers

Table 3.6 Essential Question, Overarching Idea, and Core Concepts of Human Body Unit

Essential Question	How do the human body systems interact with each other?
Big idea	Human body systems work together
Core Concepts	1. Basic understanding of the digestive, respiratory, and muscular systems 2. Interactive nature of the digestive, respiratory, and muscular systems 3. Process of diffusion/osmosis

Data Collection

Data were collected through a variety of sources during the two units over sixteen weeks, including non-participant observations, semi-structured interviews, students' writing samples (journals, presentations, pre-tests, and summary writing), and researcher's field notes. As Patton (2001) points out, "multiple sources of information are sought and used because no single source of information can be trusted to provide a comprehensive perspective…By using a combination of observations, interviewing, and document analysis, the fieldworker is able to use different data sources to validate and cross-check findings" (p. 306). Along these lines, multiple data sources were triangulated across different sources in order to seek whether a phenomenon stays the same "at other times, in other spaces, or as persons interact differently" (Stake, 1995, p.112). Table 3.7 provides a summary of the four different data sources and the purpose of each data source.

Each data source is described in more detail below. Following these descriptions is an explanation of how they were analyzed by combining different analytical approaches to address the research questions.

Table 3.7 Data Type, Source, and Purpose Collected in Two Units over Sixteen Weeks

Data Type	**Data Source**	**Purpose**
Non-Participant Observation	Whole class; small groups	--To access how students constructed knowledge in different talk-to-learn and writing-to-learn activities; to provide data on how students interacted with other students and teacher
Semi-Structured Interview	Before learning the unit interview	--To understand students' prior knowledge before learning the units (ecosystem and human body system)
	Combination with observations during the units	--To understand the rationale behind students' actions, arguments, talk, and writing; to explicitly understand students' perceptions about the talking-to-learn and writing-to -learn activities and the interactions in the class
	After learning the unit interview	--To access what students had learned after the units; to externalize students' reflection on the whole unit about the function and role of talk and writing from a holistic view
Student Writing Sample	Journals; group presentations; pre-test of two units; summary writing tasks	--To understand how students used writing as a learning tool to construct scientific knowledge; to access students' performance; to understand what students knew before, during, and after the topic
Field Notes	Daily journal	--To illustrate what the video camera cannot record in terms of the limitation of technology in a "noisy" classroom; to illustrate what the researcher saw, what the researcher perceived, and how students interacted with others in that context

Non-Participant Observation

Two subject units—ecosystem and human body system—were observed over sixteen weeks using a non-participant observation method. The classroom observation allowed the researcher to investigate the full classroom discussion, the interaction among students and teachers, and the way students used talk and writing in a whole class setting and in small groups. Because the school had science class every day and this study attempted to capture the characteristics and the patterns of the combinations of talk and writing that emerged as the students constructed their understandings of scientific concepts in a variety of activities, the science class was videotaped daily. These activities included, but were not limited to, the five phases of the SWH approach, which are: beginning ideas/ inquiry question, test/ observation, claim/ evidence, reading, and reflection. Table 3.8 provides an overview of the classroom activities by day and the amount of time spent on each activity for sixteen weeks. The total number of classroom observations was 74.

A video camera placed in the corner of the classroom recorded all classroom activities when students participated in a whole class discussion or activities. When students had group discussion, three video cameras were used to capture the three target students' (Blair, Kurt, and Nolan) interactions in their groups.

Table 3.8 Argument-Based Classroom Activities by Day

Week	Day				
	Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**
1	Beginning Ideas	Beginning Ideas	Concept Mapping Activity	Inquiry Questions	Inquiry Questions
2	Discuss Variables	Test/ Observation/ Whole Class Discussion/ Small Group Discussion			
3	Sharing Results	Write Group Claim & Evidence	Unit 1: 1st Negotiation	Revise Group Claim & Evidence	Revise Group Claim & Evidence
4	Unit 1: 2nd Negotiation			Whole Class Discussion/ Small Group Discussion/ Lecture	
5	Revise Group Claim & Evidence	Unit 1: 3rd Negotiation		Reading (what experts say)/ Whole Class Discussion	
6	Reflection/ Whole Class Discussion		Concept Mapping Activity	Summary Writing	Summary Writing
7	Beginning Ideas	Inquiry Question	Deer Activity		Whole Class Discussion
8	Write Letters to Fourth Graders	Whole Class Discussion	Write Letters to Fourth Graders	Feedback from Peers	No Class
9	Beginning Ideas	Beginning Ideas	Concept Mapping Activity	Inquiry Questions	Inquiry Questions
10	Test/ Observation/ Whole Class Discussion/ Small Group Discussion				
11	Analyze Data		No Class		
12	Write Group Claim & Evidence		Unit 2: 1st Negotiation		
13	Whole Class Discussion/ Small Group Discussion/ Lecture		Concept Mapping Activity		No Class
14	Test/ Observation/ Whole Class Discussion/ Small Group Discussion				
15	Write Group Claim & Evidence		Unit 2: 2nd Negotiation		Revise Group Claim & Evidence
16	Reading (what experts say)/ Whole Class Discussion/ Small Group Discussion		Reflection/ Whole Class Discussion/ Small Group Discussion		Summary Writing

Note 1: Unit 1 (ecosystem): 1-8 weeks (1-6: plant investigation; 7-8: population fluctuations); Unit 2 (human body system): 9-16 weeks (9-12: digestive system; 13-16: respiratory system).

Note 2: The first research question focuses on public negotiation, which included 11 classes. The second research question attempts to capture the characteristics and patterns of the combination of talk and writing in a variety of activities, which included 74 classes in total.

Semi-Structured Interview

Interviewing is one of the most powerful ways to begin to understand the world from the subjects' points of view, to reveal the meaning of people's experiences, and to uncover their lived world (Kvale, 1996). In other words, it is not possible to observe everything by using classroom observation, so interviews can provide access to the context of students' actions (Seidman, 1998), and thereby provide the researcher with a way to understand the meaning of those actions. In this respect, interviews were conducted in this study to find out what students knew and why they acted in particular ways when completing the assigned activities.

Three different types of interviews were carried out to gain an in-depth understanding of the target students' development regarding the nature of argumentation and their perceptions of the function and role of talk and writing in an argument-based inquiry classroom. The first round of interviews was conducted before students learned the topic. The purpose of the first interview was to identify the students' prior knowledge of the topic, the kind of learning style each student performed, what they thought about talk and writing as they learned science concepts, and what sort of talk and writing they typically did as they learned science concepts.

The second round of interviews was conducted in combination with observations after each class. The second interviews focused on the concepts students learned in class, as well as on the students' explanations of how they learned the concepts and of their actions during the class. Based upon the researcher's previous study (Chen, Hand, & Park, 2011), this round of interviews was critical for understanding the reasons why students accepted alternative arguments and created other models to represent their ideas, and how they perceived the function of talk and writing in a specific moment.

The third round interview was conducted at the end of each unit. The third round interviews focused on the students' reflection on the whole process of knowledge construction and the nature of argumentation from a holistic view.

Each interview lasted between 10-20 minutes. The total number of interviews for three rounds during two units was 66, as shown in Table 3.9. All interviews were videotaped and transcribed. To develop interview questions for three rounds, the researcher created a table that summarizes how he came to know what he wanted to know, as shown in Table 3.10. The interview questions for three rounds can be found in Appendix A.

Table 3. 9 The Number of Interviews for Each Student

Student/Unit	Unit 1-Ecosystem	Unit2-Human Body System
*Kurt	8	9
*Nolan	6	6
*Blair	7	6
Ryan	4	4
Mike	4	4
Oliver	4	4
Total	33	33

Note 1: * Indicates that the student was selected to participate in the second research question

Note 2: Students were interviewed after each class during a 30 minute break; therefore, there was some variation in how frequently the students participated in the interview process

Table 3.10 The Matrix of Research Questions and Interview Questions

Research Questions/ What the researcher wants to find out	**How can the researcher learn this from interviews**
Research Question 1: How do students develop an understanding of the components of argumentation in public negotiations over time when participating in an argument-based inquiry classroom?	
1. How do students develop the nature of argumentation for public negotiation?	--How would you describe to a fourth grader what a claim is? --How would you describe to a fourth grader what evidence is? --How would you describe to a fourth grader what negotiation is? --What is the most important thing when you participate in negotiation? --How do you perceive the difference between the end and the beginning of the semester in terms of negotiation in a whole class?
2. How do students develop an understanding of the argument structure of writing?	--How do you come up with or create a claim? --How do you get or find evidence for what you study in science class? --How can you describe what a good claim is? --How can you describe what good evidence is? --What is the difference between data and evidence?
Research Question 2: In what ways do talk and writing support scientific knowledge construction in an argument-based inquiry classroom?	
1. How does talk contribute to student knowledge construction?	--I noticed in this science class that lots of people talk. Why do all of you talk so much in this science class? -Do you think talking with your classmates helps you understand something? -What do you think your role is in whole class discussion/ a small group discussion?
2. How does writing contribute to student knowledge construction?	--I noticed in this science class that you sometimes write things in your journal. Why do you write things down in this class? --When you write in your science journal, where do most of those ideas that you write about come from? --How do you think writing helps you to understand something?
3. How do talking and writing interact with each other?	--I noticed in this science class that you sometimes write things before you talk; why do you write down your ideas before you talk? --Do you think writing down something before you talk helps you learn something? How? Why? --Do you change your ideas after talking in the science class? Why do you want to change your ideas?

Writing Sample

As the purpose of this study centered on students' talking and writing, students' writing samples were critical to help in answering the research questions. Students' writing samples were collected to examine what they wrote before, during, and after discussions with their peers, and to reveal what they knew about particular concepts. Students' writing samples included students' journals, group presentations, pre-tests, and summary writing tasks.

In this class, students were asked to have their own journal in which they could write down anything they wanted. Therefore, students' journals allowed the researcher to understand how they used writing to build their knowledge daily. The group presentation allowed the researcher to capture their understanding of the argument structure for each public negotiation. Students' pre-test answers and summary writing allowed access to what students knew before and after each unit. Pre-test answers and summary writing also allowed the researcher to capture the progress of students' understanding of argument structures.

In addition, informal interviews were conducted with students about their writing samples to understand the reasons they wrote, drew, and organized datasets in particular ways.

Researcher's Field Notes

As Patton (2001) points out, "field notes are the fundamental database for constructing case studies and carrying out thematic cross-case analysis in qualitative research." Field notes consist of descriptions of "what is being experienced and observed, quotation from the people observed, the observer's feeling and reaction to what is observed, and field-generated insights and interpretations" (p. 305). In this study, the researcher recorded field notes on a laptop during and immediately after each classroom observation. After returning from the research site, a reflection journal was compiled for preliminary analysis of the observations and interviews.

Because it was not possible to observe everything, the researcher, as an observer, generated an observational framework from his previous study (Chen, Hand, & McDowell, 2011) to focus on what needed observation (see Table 3.11).

Table 3.11 General Observation Framework

Category	Dimension	Sub-Dimension	Description
Argument	Claim	Accuracy	--The extent to which claim is correct
		Alignment	--The extent to which claim is targeted to the inquiry question
	Evidence	Type	--The type of evidence that students use to support claim --Use of rebuttal
		Support	--The extent to which claim is explained by evidence
		Sufficiency	--The amount of evidence students use
Dialogue Interaction	Complexity of Question/		--The extent to which students question, support, reject, and critique peers' ideas
	Idea Exchange		--The extent to which students compare their ideas to others
Use of Writing	Function		--The ways in which students use writing to learn

Data Analysis

The research questions for this study were: (1) How do students develop an understanding of the components of argumentation for public negotiations over time when participating in an argument-based inquiry classroom? (2) In what ways do talk and writing support scientific knowledge construction in an argument-based inquiry classroom? To answer the first question, two different analytical approaches were used: (a) the constant comparative method (Strauss & Corbin, 1990) and (b) the enumerative approach (LeCompte & Preissle, 1993). By conducting two analytical approaches to the same data set, methodological triangulation was carried out and the consistency of qualitative coding patterns and interpretations was strengthened.

To answer the second question and to explicitly capture the targeted students' knowledge construction trajectories, the researcher designed a purposeful approach to understand how the targeted students used talk and/or writing to build their scientific knowledge. This approach is called in-depth analysis of knowledge construction trajectory (KCT) episodes.

Constant Comparative Method

In the constant comparative method (Strauss & Corbin, 1990), the data analysis focuses on the identification of similar and different patterns by comparing one segment of data with another. Strauss and Corbin (1990) describe some flexible guidelines for coding data, which include open coding, axial coding, and selective coding. Based upon the three guidelines for coding, the reseacher developed a five-stage analytical procedure from the multiple sources of data: (1) comparison within a single observation transcript, (2) comparison among different observation transcripts within the same unit, (3) comparison of observation transcripts from different units, (4) repeating the same procedures for comparison of interviews, field notes, and writing samples, and (5) comparison of observation transcripts, interviews, field notes, and writing samples. Each step is summarized in Table 3.12. The coding schemes for the analysis of multiple sources of data were established by the researcher; therefore, the analysis did not utilize pre-existing coding schemes. In each stage, two senior researchers were invited to examine the coding schemes and check the appropriateness and credibility of the interpretations.

In each stage, the researcher consistently asked a series of questions in order to understand the characteristics and unfolding changes of students' understanding of argumentation components in that context over time. This strategy is suggested by several researchers who have used the constant comparative method to better understand and thoughtfully interpret the results of that context (Boeije, 2002; Wu, 2002). These questions are listed in Table 3.12.

Before coding the multiple sources of data, first, all classroom videotapes were transcribed and each transcript was broken into utterances. An utterance represented a unique idea or contribution to the discussion. An individual's talk or writing could consist of one utterance or multiple utterances depending on how many ideas were included in one segment of talk or writing. It was assumed that each utterance or analysis unit represented a certain form of student thinking, reasoning, or idea. Hence, codes were assigned for the function that they served in the text or the meaning or the idea that they conveyed in the text. Similar strategies have been previously used by researchers to analyze student talk and writing (Keys, 1999; McNeill & Pimentel, 2010; Peker & Wallace, 2009).

Table 3.12 Different Steps in the Constant Comparative Analysis Procedure

Type of Comparison	**Analysis Activities**	**Goal**	**Questions**
Stage 1: Comparison within a single observation transcript	--Open coding --Interpreting the initial patterns	-- Developing categories	--What is the core message of the observation transcript? --Are the coding categories appropriate to reflect the students' understanding of argumentation? --Does each utterance code appropriately?
Stage 2: Comparison among different observation transcripts within the same unit	--Axial coding --Shape the criteria of codes	--Making connections between categories	--What are similarities and differences among different observation transcripts? --What combinations and branches of codes occur? --Where do temporary themes occur?
Stage 3: Comparison of observation transcripts from two units	--Selective coding --Testing the relationship of each category	--Conceptualizing the categories' relationship -- Understanding the patterns over time --Generalizing temporary themes	--Can the axial coding schemes apply in the second unit? --What are the overall patterns and the storyline of students' argumentation in public negotiations over time?
Stage 4: Repeating the same procedures on other sources of data	--Triangulating data sources	--Finding consensus on the interpretations	--What themes appear from other sources? --What and how does the evidence from other sources support the interpretation based upon observation of transcripts?
Stage 5: Comparison among different data sources	-- Categorizing temporary themes	--Generalizing and testing themes	--What patterns exist from the multiple sources of data? -- What are the possible reasons to explain the theme?

Step 1: Comparison within a single observation transcript

At the start of the research, the comparison was conducted within one observation. Open coding was undertaken in this step. Every utterance of the observation transcripts was studied to determine what exactly had been said and to label each passage with an adequate code. By comparing different parts of the observation transcript, the consistency of the observation transcript as a whole was iteratively examined. For instance, if one student's talk, "Aren't you changing more variables, and like, water?" was coded as *"challenging"* in the beginning of the step, the other student's similar talk, "Did the one you didn't put any water on grow?" was coded as *"information seeking"* later. Clarification and re-coding about these two utterances were needed to make consistent observations of the whole transcript. Therefore, these two utterances were finally coded as *"information seeking."*

The purpose of this internal comparison in the context of the open coding process was to develop categories and label them with the most appropriate codes. In this way, the comparison "leads to tentative categories that are then compared to each other and to other instances" (p. 159, Merriam, 1998), until temporary themes can be formulated. It represents an attempt to interpret the parts of the observation in the context of the entire story. Some temporary themes were generated by looking at the patterns of the single observation transcript.

Step 2: Comparison among different observation transcripts within the same unit

Six observation transcripts related to pubic negotiation in the first unit were treated as described above. As a result, extra codes were developed due to different dialogues and more complex arguments occurring in these transcripts. For example, using evidence-based talk to support and reject an argument did not occur in the first step, but did occur in this step. New codes were then generated. As soon as the six observation transcripts had been coded, comparison among the six observation transcripts was conducted to identify the regularities and the tendencies in different classes over time. Additionally, comparing these six classes in the first unit could be constructed as a group of codes based upon similar criteria, concepts, and meanings. However, some cases revealed the necessity of dividing one code into two or three sub-codes because more codes could explain the patterns in that context. For example, *"challenging"* was initially generated in the first step. Nevertheless, when students' dialogue became more complex over time, other sub-codes, such as "*challenging the relationship between claim and evidence"* and "*challenging the relationship between question and claim"* needed to be generated to describe the patterns oriented to the research question. The purpose of this step was to further develop axial coding to document any potential changes in the ways in which students participated in scientific argumentation.

Step 3: Comparison of observation transcripts from two units

Selective coding was conducted in this stage. The process entailed "selecting the core category, systematically relating it to other categories, validating those relationships, and filling in categories that need further refinement and development" (Strauss & Corbin, 1990, p. 116). The axial codes generated in step 2 were applied to the second unit, including five classes of observation transcripts, to examine whether the coding schemes could be applied in the other unit.

The comparison between the two units allowed the researcher to look at the big picture and construct a storyline about the change in students' understanding of the nature of argumentation over time. The purpose of this step was to gain greater knowledge about the tendencies and themes of students' argumentation patterns as well as to refine the coding schemes. Table 3.13 shows the codebook, which includes descriptions and examples related to students' public negotiations in an argument-based inquiry classroom.

Table 3.13 Codebook for Students' Public Negotiations

Categories	**Sub-Categories**	**Description**	**Example**
Information Seeking		Any response used by an individual to gather more information from others	-- Do you know what the heights of the plants were?
Elaborating		Any response used by an individual to clarify or expand his/her own ideas or argument about a concept or task	--What I'm trying to say, you can't just like fill the cup to like the brim of water and expect it to grow.
Challenging		Any response used by an individual to critique others' ideas or arguments	
	Test	Test Process: devise a question which is focused on test process or test design	-- But that's changing another variable.
	Relationship	Question-Claim: devise a question which is focused on the question/claim relationship	--Do you think your claim answers the question?
		Big idea-Claim: devise a question which is focused on the big idea/claim relationship	--Your evidence supports your claim, but your claim doesn't relate to the big idea. The claim is food goes through the steps to allow your body to absorb energy from food. The big idea is human body systems work together. Your claim has nothing to do with human body systems.
		Claim-Evidence: devise a question which is focused on the claim/evidence relationship	-- I don't think your evidence supported your claim. Because the focus of your claim is food's broken down and energy is absorbed. Are you showing how you know that food has energy and it's absorbed into the body?
	Value	Claim: devise a question which is focused on claim accuracy	-- I don't get your claim. Do seeds need correct temperature or warmth?
		Evidence: devise a question which is focused on evidence (1) sufficiency (2) validity (3) reasoning	-- Sufficiency: I think you need to provide more evidence to support the claim.

Table 3.13-continued

Categories	**Sub-Categories**	**Description**	**Example**
			--Validity: How do you know that there are actually muscles and bones that work with the respiratory system? --Reasoning: Your evidence doesn't help us. It just says the diaphragm helps to get air in and out of your body. That doesn't tell us how.
	Condition	Give an assumption, situation, or example which is different or conflicts with the individual's ideas	-- If they don't need sunlight or darkness to germinate, then where do you put them?
	Compare	Provide an alternative idea which is different or conflicts with the individual's ideas	-- The other classes put it in dark spots, and it still grew.
Defending		Any response used by an individual to persuade others about his/her ideas	
	Simple Answer	Any response used by an individual is simple, lacking further elaboration	--It's not just for the next step, it's for everything.
	Evidence-based	Any response used by an individual is supported by evidence	-- First the teeth chew up the food, the tongue pushes the food up to the teeth, the saliva breaks down the food even more...and then the food goes into the small intestine.
Supporting		Any response used by an individual to accept or agree with someone else's ideas	
	Simple supporting	Any response used by an individual to accept or agree with someone else's ideas without further elaboration	-- I agree with Jaden.
	Evidence-based	Any response used by an individual to accept or agree with someone else's ideas supported by evidence	-- Yeah, when a seed is under the soil, it doesn't get any sunlight; depending on how far deep you put it, it can't get to the sunlight but it can get to the heat the sunlight's producing.

Table 3.13-continued

Categories	Sub-Categories	Description	Example
Rejecting		Any response used by an individual to disagree with all or part of the speaker's ideas	
	Simple rejecting	Any response used by an individual to disagree without further elaboration	-- No, it doesn't!
	Evidence-based	Any response used by an individual to disagree supported by evidence	-- I disagree with sunlight because I think the seed gets its nutrients in the seed, and when it gets water, it like, cracks open and then it gets oxygen.

Step 4: Repeating the same procedures on other sources of data

It is important to give data triangulation a central place in qualitative analysis (Patton, 2001). In the fourth step, interviews from six students and field notes from daily recording were analyzed following the previous three steps. Six aspects related to their perspectives of argumentation emerged. The codebook is shown in Table 3.14. Students' writing samples were analyzed in the same way to identify some core argument components. Five core components related to students' written arguments were identified, including accuracy of a claim, sufficiency of evidence, reasoning of evidence, relationship between a claim and question, and relationship between a claim and evidence. However, to gain a better understanding of the change in the quality of students' written arguments over time, a writing rubric was created based upon the core argument components. Each component was rated using a five-point scale from 0= "Lack" to 4= "Proficient" for a possible total of 20 points for the instrument as a whole.

The codes were then compared or contrasted across different data sets to arrive at a better understanding of the reason, tendency, and interpretation of students' understanding of the nature of argumentation for public negotiations during two units.

Table 3.14 Codebook for Students' Interview and Field Notes

Categories	Description	Example
Meaning of negotiation	Any response or idea related to the understanding of negotiation	-- Negotiation is where you talk back and forth. It just can't be one person - it's like a conversation but you argue, hopefully come to agreement.
Function of talk	Any response or idea related to the understanding of the role and the use of talk to construct scientific knowledge	-- I like talk because it is easy to show my ideas to others. -- The beginning of the year, we weren't really talking then we fell behind, and I'm guessing it's probably because of us going, "Okay, we'll change that."
Function of writing	Any response or idea related to the understanding of the role and the use of writing to construct scientific knowledge	-- If everything is neat and organized and all that stuff, it gets you farther in the project. -- Drawing a picture is a good way to explain my idea.
Argument structure	Any response or idea related to the understanding of the argument components or structure: (1) data (2) claim (3) evidence (4) reasoning (5) the relationship between question and claim (6) the relationship between claim and evidence	-- Data is part of evidence. -- I don't exactly know why it's called evidence. -- If the evidence has nothing to do with the topic, if the evidence has nothing to do with the claim, then I don't think that's very good evidence.
Reason to shift ideas	Any response or idea showing why the student is willing to accept, change or shift the original idea to a new idea	-- Andrea made a good example and explanation when she showed us that model, because that model shows the diaphragm does not even come close to touching the lung and how the lungs work, I agree with that now.
View of feedback	Any response or idea related to student's conception of feedback from peers or teachers	-- I don't really care what they say. I like to stay with my idea. -- The person that's telling the comment has to say why they agree or disagree with you.

Table 3.15 Argument-Based Writing Rubric

Component	Level of performance				
	Lack (0)	Limited (1)	Basic (2)	Proficient (3)	Exemplary (4)
Claim _ Accuracy	Does not make a claim	Makes a scientifically incorrect claim	Makes a scientifically correct claim, but does not catch the essence of the investigation	Makes a scientifically correct claim, and partially catches the essence of the investigation	Makes a scientifically correct claim and completely catches the essence of the investigation
Evidence _ Sufficiency	Does not provide evidence	Provides one piece of evidence	Provides two pieces of evidence	Provides three pieces of evidence, including rebuttal	Provides more than three pieces of evidence, and makes a rebuttal
Evidence _ Reasoning	Does not provide explanation, or just rephrases the claim	Provides inappropriate and inadequate explanation, or just reports data as evidence	Provides appropriate but inadequate explanation	Provides appropriate and adequate explanation partially based on interpretation of investigation data	Provides appropriate and adequate explanation completely based on interpretation of investigation data
Relationship between Claim and Question	Does not make connection between claim and question	Makes weak connection between claim and question	Makes moderate connection between claim and question	Makes strong connection between claim and question	Makes strong and sophisticated connection between claim and question
Relationship between Claim and Evidence	Does not make connection between claim and evidence	Makes weak connection between claim and evidence	Makes moderate connection between claim and evidence	Makes strong connection between claim and evidence	Makes strong and sophisticated connection between claim and evidence

Stage 5: Comprising observation transcripts, interviews, field notes and writing samples

The final stage of comparison involved the synthesis of multiple sources of data that were analyzed in the previous four steps. First, the researcher repeatedly reviewed the temporary themes with evidence generated from different data sources, and then sought to categorize similar themes across different types of data source in the same group in order to reorganize them to foreground the findings in order to answer the research question. Figure 3.1 shows an example of how the final theme was generated from temporary themes across three different sources of data. For instance, three temporary themes from classroom observation, students' interviews, and students' writing samples were related to the trend of using rigorous evidence to debate, articulate, and express arguments. They were collapsed together to reshape the themes that illustrated similar ideas. In this way, the main themes could be triangulated across various data sources and could confirm the credibility of the interpretations.

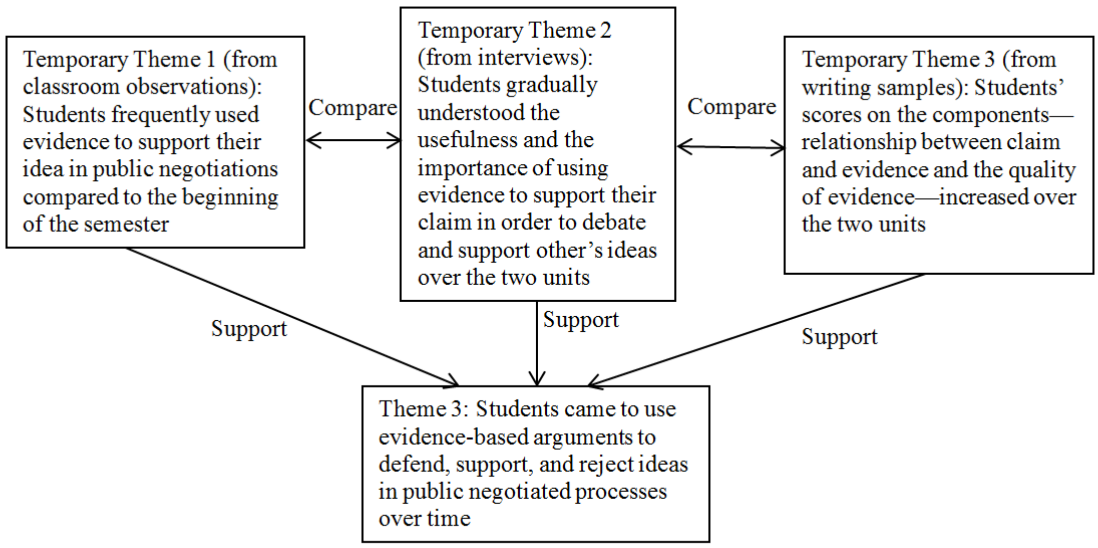


Figure 3.1 Themes Supported by Temporary Themes across Different Sources of Data

Enumerative Analytical Approach

The enumerative analysis approach (LeCompte & Preissle, 1993) was employed to reduce the subjectiveness of qualitative interpretations and to facilitate identifying the characteristics of students' understandings of the nature of argumentation. The function of the enumerative approach is to quantify verbal data so as to explicitly capture the patterns emerging from coding schemes. The results from the enumerative analytical approach were compared with and integrated into the results from the constant comparative method so as to provide methodological triangulation (Denzin, 1978).

Because the first research question addressed the way in which students developed their understanding of the nature of argumentation for public negotiations, the researcher mainly conducted the enumerative analytical approach on observation transcripts. First, this involved counting the frequency of codes generated by the constant comparative method for each observation transcript related to public negotiated activities. Second, the frequency of codes in the same category across five rounds of negotiated activities in two units was compared. In doing so, the overall picture and regularities could be easily captured in terms of each category. Then, temporary themes were created from the overall picture. Finally, a comparison between the temporary themes and the themes generated by the constant comparative method was conducted. Figure 3.2 shows an example of how two themes were compared using different methods, and then illustrates the final themes produced. Again, two senior researchers were invited to examine whether the final themes were appropriate and addressed the research question.

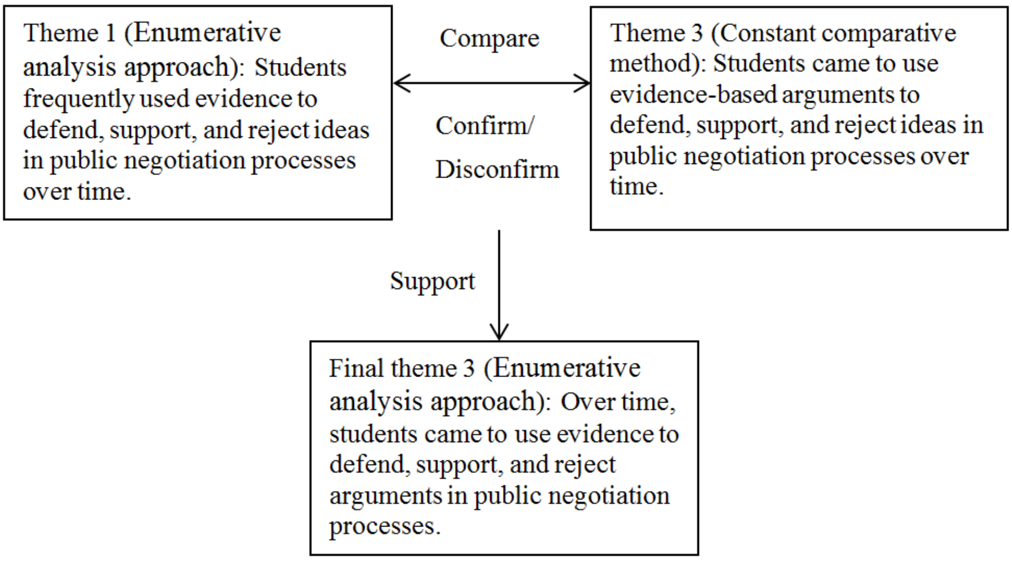


Figure 3.2 Themes Compared and Supported by Two Different Analytical Methods

In-Depth Analysis of Knowledge Construction Trajectory (KCT) Episodes

The second research question focused on how students construct their scientific knowledge by using talk and/or writing as learning tools in an argument-based inquiry classroom. Simply employing the constant comparative method and the enumerative approach did capture *both* the development process of student knowledge construction *and* the way students use talk and/or writing as learning tools to construct that knowledge. Boeije (2002) has illustrated that the art of qualitative research has to do with creative processes and with the interplay between data and researchers when gathering and analyzing data. Hence, a purposeful approach was designed to answer the second research question, consequently called in-depth analysis of knowledge construction trajectory (KCT) episode.

Four analysis procedures from the multiple sources of data were developed: (1) dividing units into classes and identifying activities within a class, (2) identifying events within an activity, (3) synthesizing events into episodes, and (4) analyzing data related to the episode by the constant comparative method and the enumerative approach, which are shown in Figure 3.3.

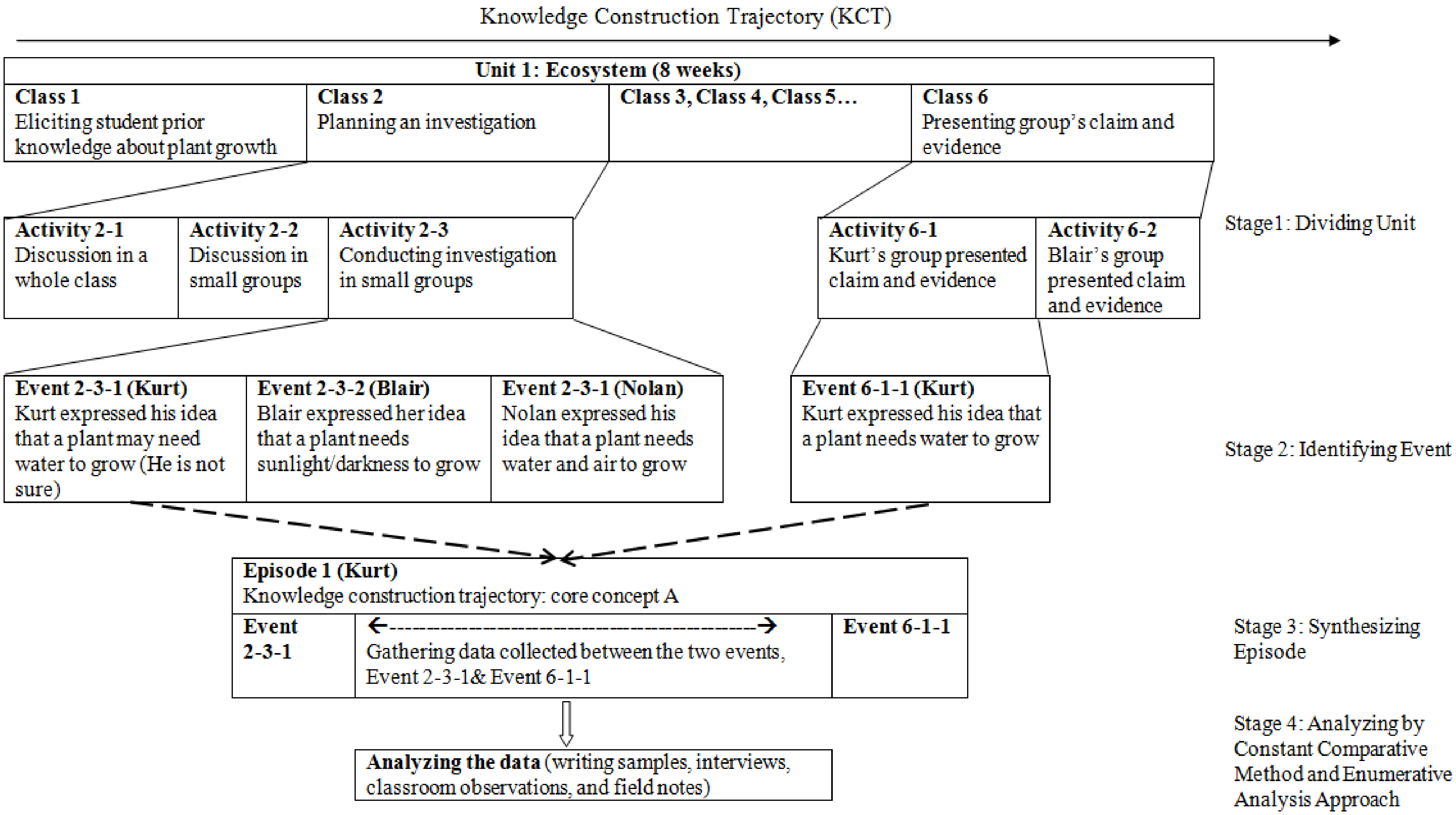


Figure 3.3 In-Depth Analysis of Knowledge Construction Trajectory (KCT) Episodes

Stage 1: Dividing units

Dividing units was intended to reduce data to "units of analysis" (LeCompte, 2000), "the smallest piece of information about something that can stand by itself" (Lincoln & Guba, 1985, p. 345). The researcher first reviewed the field notes and created an overview of the whole period of teaching units, dividing the units by class. Each class may have included several activities such as a whole class discussion, investigation, and presentation, which are defined as a bounded set of the teaching strategies in a given class (Jordan & Henderson, 1995). Figure 3.3 shows an example of how three main activities were identified in Class 2, including discussion in a whole class, discussing in small groups, and conducting investigation in small groups. This identification allowed for an easy examination of the data and location of what particular activities and strategies occurred in that class.

Stage 2: Identifying events

In Stage 2, each activity was broken down into events. Once students comprehended or attempted to grasp any core concepts in each activity, an event could be identified. That is, an event could constitute any conversation or verbal expression in which students engage with, debate, discuss, defend, or write down a position related to the core concepts of the unit. After an event was identified, it was described based upon three perspectives: (a) core concepts related to this event, (b) what the student did, and (c) why the student did what he/she did. The description was based on the data related to the event such as observations or students' writing samples from the classroom. For example, Figure 3.3 shows how three events from Activity 2-3 and one event from Activity 6-1 were identified. In Activity 2-3, the researcher first perceived that Kurt, Blair and Nolan expressed their ideas about the core concept related to plant investigation, respectively, when they were conducting their investigation in small groups. Later in Activity 6-1, when they were asked to represent their group's claim and evidence to the whole class, the researcher recognized that Kurt explicitly talked about his idea related to the core concept he discussed in Activity 2-3 and showed his conceptual growth. The event 6-1-1 was then identified.

Stage 3: Synthesizing episode

The third stage involved collecting events related to the same core concept for each student into an episode. For example, as shown in Figure 3.3, event 2-3-1 and event 6-1-1 are related to constructing the same core concept in unit 1 by the same student, Kurt. These two events were then gathered as episode 1. According to Jordan and Henderson (1995), episodes are "smaller units of coherent interaction within events" (p. 57) which are equivalent to "chunk(s) of meanings" according to Lincoln and Guba (1985) and "nodes" in a study by Barab et al. (2001). This stage analysis made a range of events visible and allowed for the identification of the trajectory of knowledge construction based upon the analysis of episodes.

Stage 4: Analyzing data by the constant comparative method and the enumerative approach

Once an episode revealed a student's growth in understanding of a science concept, all relevant data such as writing samples, interviews, classroom observations, and field notes collected between the events that constituted the episode were retrieved and analyzed using the constant comparative method (Strauss & Corbin, 1990) and the enumerative analytical approach to understand how writing and talk influenced that conceptual growth. Table 3.16 shows the codebook generated from reviewing and analyzing multiple sources of data.

Among 74 classroom videotapes collected from two units, 46 tapes were identified in KCT episodes and analyzed. 36 interviews and 3 targeted students' journals related to KCT episodes were analyzed. Appendix B shows an example of how a KCT episode was analyzed by using the coding schemes and thick descriptions.

After analyzing all episodes for each student across two units, the researcher repeatedly reviewed the data corpus to test and generate themes supported by different KCT episodes from different students. The purpose of reviewing the KCT episodes was to seek confirming and disconfirming evidence to triangulate the themes and increase credibility.

Table 3.16 Codebook for Classroom Observations, Interview, Writing Samples, and Field Notes

Categories	Description	Example
Expressing	Share/exchange information, ideas, claim, or evidence without any debate or negotiations	-- During the investigation, Blair seemed to like to express and share her ideas with her group members. When I asked her if I could see her journal, she looked embarrassed and said “I did not write anything” (Field notes summary, 9/29/2010)
Reporting	Present individual or group’s arguments in a whole class setting	-- We figured out that plants grow better in compost than sand (Observation, 9/30/2010)
*Recording	Capture data or translating information from observation or conversation	-- If I write down at the end of the day like, what we done about and stuff, then it helps like when I look back at it to see what we were doing (Kurt interview, 9/15/2010)
*Describing	Depict a phenomenon or investigation by writing without any reasoning or explanation	-- It needed about 30mL of water to germinate, grow. We even found out that 40 mL of water was a little too much (Kurt writing sample, 9/30/2010)
Elaborating	Any response used by an individual to clarify or expand his/her own ideas or argument about a concept or task	-- I didn't say we get our energy from grasshoppers, I said we got it from the sun (Observation, 10/21/2010)
*Organizing	Arrange one’s ideas, data, and information in a logical way	See appendix B (Nolan writing sample, 9/30/2010)
Challenging	Any response used by an individual to critique others’ ideas or arguments	--We don’t always just blow it down your windpipe (Observation, 12/1/2010)
Comparing	Provide an alternative idea which is different or conflicts with individual’s idea	--The other class put it in dark spots, and it still grew (Observation, 10/1/2010)

*Means that the cognitive action process particularly occurs in writing activities.

Table 3.16-continued

Categories	Description	Example
Reflecting	Looks back on one's actions, talk, or writing	--They tore it apart and said our evidence doesn't support the claim. They're like, "How do you know this?" We're like, "We don't know this for sure," and they're like "Why'd you put it?" Should we change our claim? (Observation, 11/30/2010)
Integrating	Put different ideas together to formulate new ideas	--I am good at putting different ideas in one. Like Kurt said… (Interview, 12/1/2010)
Stimulating Alternative Ideas	New idea is spurred by interaction with peers or writing-to-learn activities	--When I talked with Megan, she explained to me her idea. I have another idea coming out (Blair interview, 11/23/2010)
Defending	Any response used by individual to persuade others about his/her ideas	--We know this because you can't stop moving unless you die. Even if you try not to move, your heart is pumping (Observation, 12/14/2010)
*Multi-model Representing	Use more than one model (text) to show, explain, clarify, or organize one's ideas	--See appendix C (Nolan writing sample, 11/30/2010)
Audience Awareness	Consider one's ideas and explanation understandable for the potential readers or audiences	-- We have to explain this; they will ask us about how the digestive system works with other body systems (Observation, 11/30/2010)
Analogizing	Transfer information or meaning from a particular subject to another particular subject in order to explain or clarify one's ideas	--See Figure 4. (Kurt writing sample, 12/14/2010)

*Means that the cognitive action process particularly occurs in writing activities.

Issues of Trustworthiness

Trustworthiness implies that the researchers control tendencies of potential bias in the design, implementation, and interpretation of the information. To ensure the quality of this study, four dimensions and criteria of trustworthiness reframed by Lincoln and Guba (1985) were used. They reframed the conventional concepts of internal validity, external validity, reliability, and generalizability into credibility, transferability, dependability, and confirmability, as shown in Table 3.17. It is essential for the researchers to operationalize criteria for trustworthiness throughout the research process (Lincoln & Guba, 1985).

Table 3.17 Dimensions, Definition, and Strategies for Trustworthiness

Dimension of trustworthiness	**Credibility**	**Transferability**	**Dependability**	**Objectivity**
Conventional approach	**Internal Validity**	**External Validity**	**Reliability**	**Confirmability**
Question	How do we know whether to have confidence in the findings?	How do we know the degree to which the findings apply in other contexts?	How do we know the findings would be repeated if the study could be replicated in essentially the same way?	How do we know the degree to which the findings emerge from the context and the respondents and not solely from the researcher?
Common Strategies	-Prolonged engagement -Persistent observation -Triangulation (Sources, methods, investigators, etc.) -Negative case analysis -Member checks	-Thick description -Purposeful sampling	-Step-wise replication -Multiple researchers -Inquiry audit	-Triangulation -Reflexive journal -Audit trial
Strategies in this Study	-Observing over sixteen weeks -Building trust with participants -Taking field notes -Collecting multiple sources of data -Using more than one method to analyze the same data -Including all cases even if they were negative to the findings -Discussing with the teacher about the findings	-Providing detailed descriptions of the context and data analysis -Selecting the research site and participants purposefully	- Providing detailed descriptions of data collection process -Inviting other researchers to examine the findings -Using recording devices to capture the conversation and activities in the classroom	- Providing detailed descriptions of data collection process -Writing reflective journal entries whenever returning from research site -Using multiple sources of data to interpret the findings -Reconstructing the data systematically -Non-participation

Credibility (Internal Validity)

Credibility is the heart of trustworthiness (Patton, 2001). Credibility is defined by “how well the results capture the constructs used by the participants in a context and the particular dynamics of that context” (Moschkovich & Brenner, 2000, p. 479). Several techniques, as suggested by Lincoln and Guba (1985) and Stake (1995), were incorporated into the design of the study to ensure credibility: prolonged engagement, persistent observation, negative case analysis, triangulation, and member checking.

Prolonged engagement is "the investment of sufficient time to achieve certain purposes" (Lincoln & Guba, 1985, p. 301). The main purpose of this research was to understand how students develop their understanding of the nature of argumentation and construct scientific knowledge using talk and writing in an argument-based inquiry classroom. To achieve this, the class was observed and recorded every day during two teaching units over 16 weeks to avoid distortion. This strategy ensured, to a certain extent, that the entire procedure was captured rather than mere isolated segments.

Another strategy is persistent observation, which involves taking an analytical view of data, and looking for information to confirm or disconfirm the emerging understandings about the phenomena. To achieve this, the data were repeatedly analyzed and reviewed to search for confirming and disconfirming evidence for findings.

The third strategy is triangulation. Stake (1995) suggests that data should be triangulated by using different data sources. In this respect, data forms, in this study, included observation, interviews, writing samples, and researcher’s field notes across two teaching units. Closely aligned with the triangulation of data sources is methodological triangulation. The data were analyzed by three methods that included constant comparative methods, the enumerative approach, and in-depth analysis of knowledge construction trajectory episodes.

Negative case analysis was also used to establish the credibility of this study. Searching for negative cases that defied the pattern helped to illuminate the specific limitations of the interpretations (LeCompte & Preissle, 1993). For example, when tracking three students' (Kurt, Blair, and Nolan) knowledge construction trajectories, it became apparent that Kurt and Blair only used talk or writing as a learning tool in the beginning of the semester. However, Nolan used two learning tools to construct the core concepts at a very early stage of argumentative practice. Nolan's case prompted the researcher to carefully explore the reason he used two learning tools. After interviewing him, it was perceived that his intentions to use two learning tools were to record and report. The cognitive processes, to a certain degree, were similar to Kurt and Blair. Nolan's case led to a more thorough exploration in order to provide stronger interpretations.

Member checking was also used to add credibility to this study. According to Stake (1995), member checking is when "the actor is requested to examine rough drafts of writing where the actions or words of the actor are featured ... to review the material for accuracy and palatability" (p. 115). Once the draft of findings was completed, it was shared with the teacher in order to scrutinize data interpretations.

Transferability (External Validity)

Transferability has been described as the ability of research results to transfer to situations with similar parameters, populations and characteristics. To establish external validity, Mosckovich and Brenner (2000) suggest two strategies: thick description and purposeful sampling. Thick descriptions of the context, data collection, data analysis and results allow readers to make judgments about the applicability of the presented study. In addition, purposeful sampling can provide readers with an understanding of the rationale, information, and procedures of sampling. This study describes each step of the data collection, data analysis, and data interpretation in detail. Sample selection was purposeful based upon the research questions and literature review.

Dependability (Consistency)

Joppe (2000) defines dependability as “the extent to which results are consistent over time and an accurate representation of the total population under study” (p. 1). To assess dependability, researchers should document the process of data collection, data analysis, and data interpretations in detail. Detailed and logical descriptions of the research process allow other researchers outside the project to scrutinize the study. With this in mind, two senior researchers were invited to examine this study’s research process and findings in terms of data collection, data analysis, and data interpretations.

Objectivity (Confirmability)

The idea of objectivity assumes that a truth or independent reality exists outside of any investigation or observation. Using scientific objectivity allows researchers to stand at a distance and derive knowledge through empirical study. This study applied non-participant observation to eliminate the effect of the researcher on students’ learning of science. On the other hand, the process of data analysis involved more than one person interpreting the data. That is, the researcher analyzed the data collected from the research site and examined it for recurrent patterns and themes that illuminated the process by which students learn science in classrooms using the SWH approach. After the initial interpretation, the researcher discussed his thoughts with his advisors to reach a consensus.

The strategy of keeping a daily reflexive journal was also used in this study to examine and reduce bias to each participant and the research site.

Summary

This study attempted to achieve a better understanding of how talk and writing are integrated in ways that impact and contribute to students’ understanding of argumentation and knowledge construction in science across two units with 22 fifth graders. Guided by the theoretical framework developed in Chapter Two, this study took an interactive constructivist position and employed a qualitative study design.

Four types of data sources including classroom observations, semi-structured interviews, student writing samples, and field notes were used. To answer the first question, two different analytical approaches were conducted: the constant comparative method and the enumerative analytical approach. To address the second research question, the purposeful approach of in-depth analysis of knowledge construction trajectory (KCT) episodes was developed. Various strategies, such as collecting multiple sources of data, observing the class for a long period of time, selecting participants purposefully, and providing detailed descriptions of the setting and methods, were used to enhance the credibility, transferability, dependability, and confirmability of the study. The next chapter reports the results generated through the three analytical approaches. Three major findings including eight themes for two research questions are discussed in detail.

CHAPTER FOUR

RESULTS

The purpose of this study was to investigate how two learning tools, talk and writing, support students' understanding of argumentation components and their knowledge construction in an argument-based inquiry (SWH) classroom. The following two specific research questions were addressed: (1) How do students develop an understanding of the components of argumentation for public negotiations over time when participating in an argument-based inquiry classroom? (2) In what ways do talk and writing support scientific knowledge construction in an argument-based inquiry classroom?

Multiple sources of data were collected to answer these two research questions to triangulate the findings. Table 4.1 shows the major findings of this study, which will be discussed in the next three sections, and the data sources from which each finding was drawn. Each data source provided corroborative evidence to verify information obtained by other sources. Each finding in Table 4.1 was corroborated by at least one other kind of data in several cases. Triangulating the data collected from classroom observations, interviews, student writing samples, and field notes rendered a holistic understanding of how students learn the nature of argumentation and scientific concepts in an argument-based classroom.

This chapter consists of three sections; each discusses a major finding. First, student understandings of argumentation components as they engaged in public negotiations over one semester are examined. Second, the change in the students' ability to craft written arguments over time is discussed. Third, building on the findings of Research Question 1, the different combinations of talk and writing used to support student knowledge construction are described, followed by further discussion of how those two learning tools are interdependent of each other.

Table 4.1 Matrix of Findings and Sources for Data Triangulation

Major findings	Source of data			
	O	**I**	**W**	**F**
Question 1: How do students develop an understanding of the components of argumentation over time when participating in an argument-based inquiry classroom?				
Finding 1: Increased understanding of argumentation components in public negotiations				
1. Over time, students came to use more argumentation components and demonstrated a more sophisticated understanding of those components	X	X		X
2. Over time, by challenging each other's arguments, students came to focus on the relationship between claim and evidence as well as on the quality of evidence	X	X		X
3. Over time, students came to use evidence to defend, support, and reject arguments in public negotiation processes	X	X	X	X
4. Over time, students, both initially talkative and quiet students, came to implement argumentation components in public negotiation processes	X	X		
Finding 2: Increased ability of crafting written argument				
5. Over time, the quality of students' writing improved and became more argument-based	X	X	X	
Question 2: In what ways do talk and writing support students' scientific knowledge construction in an argument-based inquiry classroom?				
Finding 3: Five patterns of the use of talk and writing for knowledge construction and cognitive processes were identified				
6. When talk and writing were used together, student knowledge construction was greater than when only one learning tool was used	X	X	X	X
7. When talk and writing were used in sequence or simultaneously, students' higher cognitive processes provided more scaffolding than when talk and writing were used alone	X	X	X	X
8. While the use of talk and writing separately was more teacher-directed, the use of talk and writing simultaneously produced more student-directed learning		X		X

Note: O = Observation, I = Interview, W = Writing Sample, F = Field Note

Finding one: Increased understanding of the nature of argumentation components for public negotiations

Theme 1: Over time, students came to use more argumentation components and demonstrated a more sophisticated understanding of those components.

The research first examined how often students discussed their groups' claim and evidence using the argumentation components identified in this study in a whole class negotiation during one semester. Figure 4.1 displays the frequency of total utterances and the proportion of utterances made by students in five rounds of negotiation during two units. Overall, the total frequency of argumentative utterances increased from the first unit to the second unit (e.g., 1st unit: 1st round (88); 2nd round (152); 3rd round (276)/ 2nd unit: 1st round (310); 2nd round (335)). This result suggests that student participation in argumentative discussions was encouraged and elicited when students engaged in more rounds of negotiation. This point is nicely described by Ryan below:

> We negotiate and we come up together with things, instead of just presenting it and handing it in. We actually have to explain why we do this, and how we do this. We can say what we think. Then we can negotiate about it again and again and just go on from there. (Ryan interview, 10/12/2010)

Ryan's explanation indicates that students are able to build an understanding of science argument and science itself when they are provided opportunities to express their ideas. This understanding then became part of their reasoning process with the result that they were able to be comfortable and confident in answering questions that involved argument.

However, just examining the total frequency of student argumentative talk in the classroom did not provide a complete picture of the discourse patterns in terms of how the students used specific argumentation components. In this regard, the frequency and proportion of student utterances for each argumentation component were examined.

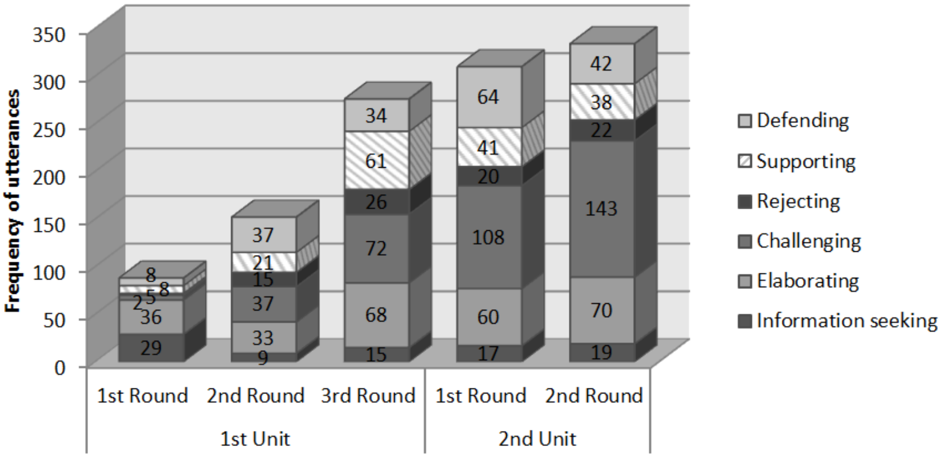


Figure 4.1 The Frequency of Argumentative Utterances Contributed by Students in Discussing Claim and Evidence in A Whole Class Setting through Sixteen Weeks

Figure 4.1 shows the frequency of student utterances for each argumentation component over five rounds of negotiations. As shown in Figure 4.1, in the first round of the first unit, 31% of total utterances were information seeking components and 41% of students' utterances were elaborating components. "Students spent a majority of their time asking questions and clarifying their understanding of the investigation, test procedures, and the variables" (Field note summary, 9/30/2010). Only a small proportion and frequency of the utterances were challenging (6%, 5), rejecting (2%, 2), supporting (9%, 8), and defending (9%, 8) responses, which are critical components of argumentative processes (Sampson, Grooms, & Walker, 2011). The following example is representative of discussions that took place in the first two rounds of the first unit (see Table 4.2).

Table 4.2 Excerpt Illustrating Student Discourse in the First-round Negotiation of the First Unit

	Classroom Discussion	Coding
Sara:	How much fertilizer did you put in each cup?	Information Seeking
Adam:	We had one with more fertilizer, one with .2 grams, and one with 1.1 grams.	Elaborating
Sara:	How many grew?	Information Seeking
Adam:	The one with no fertilizer and the one with a little fertilizer.	Elaborating
Micah:	Do you know what the heights of the plants were?	Information Seeking
Adam:	The one with no fertilizer was the shortest, but the one with a little fertilizer was 5 inches, and that was the tallest. (Observation, 9/30/2010)	Elaborating

This type of discussion was common in the first two rounds of negotiations. Although the discussion was mainly directed by students, the discourse patterns were often limited to one student who initially asked questions (Sara or Micah) and the other one who answered those questions (Adam). The triadic dialogue (Lemke, 1990) made these students rarely debate or justify the underlying reasons for a particular claim or evidence. They appeared to focus on how they gathered data from tests, rather than on interpreting data to shape evidence in support of a claim. The reason students did not frequently use argumentation components at the beginning of the semester might be because, in large part, “we [students] didn't even know what the word negotiation meant for science class” (Kurt interview, 9/15/2010). Nolan also pointed out his view about negotiation in the beginning of the semester, “I didn't really know how to do it [negotiation], like I thought that just meant like talking” (Nolan interview, 9/15/2010).

However, when students’ voices increased and students’ argumentative practice was encouraged, they were observed to challenge others’ ideas, use evidence to back up their claims, and evaluate explanatory claims in terms of evidence that they did or did not have. Figure 4.1 shows that the proportion of student utterances coded as challenging, rejecting, supporting, and defending responses in the second round of the second unit were increased to 43%, 7%, 11%, and 13 %, respectively. The frequency of student utterances coded as challenging, rejecting, supporting, and defending also increased to 143, 22, 38, and 48, respectively. The greater proportion and frequency of using argumentative responses indicate that “students were more engaged and more willing to articulate their claims and evidence, critique others’ arguments, and provide suggestions for other groups” (Field notes summary, 12/1/2010). This trend is well illustrated in the following example when students presented their claims and evidence in the first round of the unit on the digestive system (see Table 4.3).

Table 4.3 Excerpt Illustrating Student Discourse in the First-round Negotiation of the Second Unit

	Classroom Discussion	**Coding**	**Sub-Coding**
Nolan:	Each part of the digestive system works together by breaking down the food for the next part of the system... It goes through the intestine and stays there so it can compact, and then exits your body as waste.	(Presenting)	
Jeff:	Is the digestive system only for the next step?	Challenging	Evidence
Nolan:	It’s not just for the next step, it’s for everything.	Defending	Simple
Kurt:	Well, the teeth break food down into smaller pieces so it’s ready for the next step of going down in the stomach. When you swallow…	Defending	Evidence -based
Aaron:	Why is it broken down into smaller pieces? What’s the purpose of that?	Challenging	Evidence
Kurt:	Well like, if you… To make it into smaller pieces, if it went down to the esophagus, it would be easier for the stomach to break it down so it could go into the intestines.	Defending	Evidence -based
Janice:	You didn't really say how the human body systems work together, you just said like, what they do and how they work.	Rejecting	Evidence -based
Jeff:	Yeah…So the reason why we eat food is to put food through our body so we can have an end result?	Challenging	Claim-Evidence
Grey:	Oh…The reason we have a digestive system is so we can get energy…	Elaborating	
Megan:	Yeah, I agree, Grey. If you're tired, then you don't have the energy to do very many things… (Observation, 11/22/2010)	Supporting	Evidence -based

Unlike the previous example, the students were challenging, defending, rejecting, and supporting each other's ideas and claims. The challenging questions from Jeff and Aaron led to more in-depth discussion and insights into the core issues (the purpose of the digestive system) involved in the presentation. In addition, although the presentation was conducted by Kurt and Nolan, Grey and Megan helped them respond to the challenging questions to elaborate their claims and evidence. As a result, they figured out that one of the purposes of the digestive system is to get energy by breaking down food step by step. They co-constructed more complete scientific knowledge by using argumentation components during the whole class discussion. The conversation was not limited to the students in the presenting groups and the students asking questions, but expanded to include the whole class. Kurt stated his understanding about negotiation at the end of the semester by saying that, "Negotiation is kind of like a form of arguing" (Kurt, 1/13/2011). Nolan also recognized this improvement in his understanding of the meaning of negotiation. He stated that "[negotiation is] where you talk back and forth. It just can't be one person - it's like a conversation but you argue, hopefully come to agreement" (Nolan interview, 10/15/2010).

The students' shift in understanding of the meaning of negotiation was closely related to their increased emphasis on using essential argumentation components. In brief, they gradually linked the use of argumentation components with the negotiated processes.

Another interesting finding from the data analysis was that students were able to transform and continuously build argumentation abilities learned in the first unit about ecosystems to the second unit on the human body system. As shown in Figure 4.1, the frequency of challenging and defending responses increased from 72 and 34 in the first unit to 108 and 64 in the second unit. The frequency of rejecting and supporting also maintained a similar level in the third round to that in the first round.

Importantly, students used more evidence-based responses in the second unit. This point will be discussed in detail in Theme 3.

Taken together, this analysis suggests that these students were better able or more willing to use the argumentation components identified in this study to construct their scientific knowledge through five rounds of negotiations. In addition, students transformed and even continuously developed argumentative skills in terms of talk from the first unit to the second unit to construct knowledge. The argumentative skills were not eliminated due to the change of the topic context, as students quickly retrieved and screened their argumentative responses to a new situation.

Theme 2: Over time, by challenging each other's arguments, students came to focus on the relationship between claim and evidence as well as on the quality of evidence.

Studies of argumentation practices suggest that students need to understand how to play the role of critiquer appropriately, which basically involves learning how to scrutinize the explicit connections demonstrated between a claim and evidence in identifying the particular meaning of scientific concepts (Berland & Reiser, 2010; Nola, 1997). Ford (2008) underscores the importance of being a critic by stating, "construction without appropriate critique would not result in the creation of new scientific knowledge" (p. 410). This study, therefore, examined the dimensions in which students challenged each other's ideas and how often they challenged within those dimensions.

Data analysis revealed that not only did the frequency of challenging students substantially increase over time, but also the dimensions of the challenge component on which students focused distinctly shifted over five rounds of negotiations. Figure 4.2 provides the frequency and proportion of the challenge component within each aspect to which students contributed. Three main dimensions within which students challenged each other's ideas were recognized in different stages of negotiations. These dimensions were (1) the focus of the test and the accuracy of the claim, (2) the focus of the argument structure, and (3) the focus of the quality of evidence. Each dimension will be discussed further.

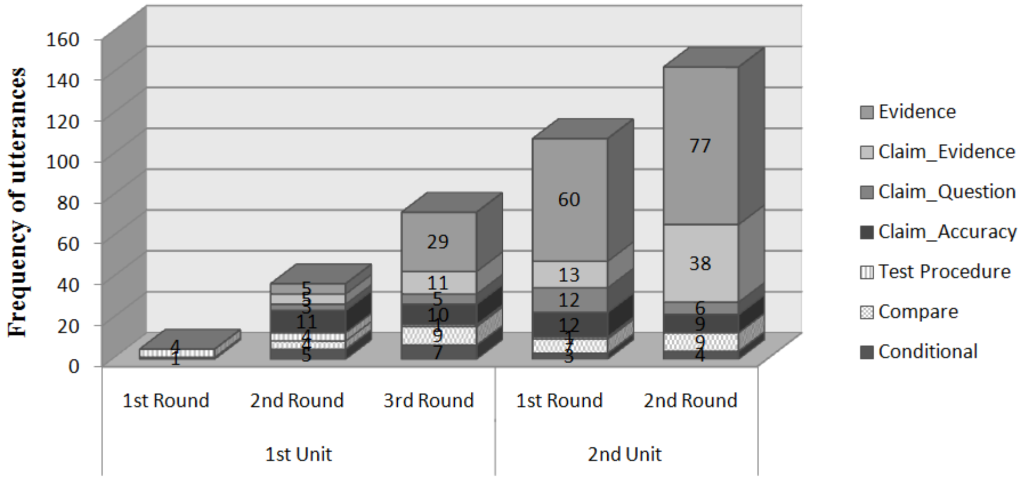


Figure 4.2 Frequency, Proportion, and Types of Challenging Responses Contributed by Students over Five Rounds of Negotiations

The test and the accuracy of the claim. As shown in Figure 4.2, most of the utterances related to the challenge component made by students during negotiation processes in the beginning of the semester were devoted to test procedures or the accuracy of claims. As noted in the field notes:

> Students attempted to challenge the validity of each group's tests and tried to understand if their claims are correct from a scientific perspective. Only a small proportion of students' conversation was focused on examining the quality of the connection between claim and evidence and the quality of evidence. (Field notes summary, 10/1/2010)

The following excerpt is representative of the challenging response made by students in the beginning of the semester (see Table 4.4).

Table 4.4 Excerpt Illustrating Student Discourse in the First-round Negotiation of the First Unit

	Classroom Discussion	Coding	Sub-Coding
Helen:	We tested to see if they can grow in different kinds of soil, and if they can grow with different amounts of water. Sometimes plants can grow without soil. And if they can, then that's another thing that we tried to test. Sometimes they can go without dying. Janice.	(Presenting)	
Janice:	Aren't you changing more variables, like soil and water?	Challenging	Test Procedure
Helen:	Well no, the same amount of water, but just like, different amounts of cups and things.	Defending	Evidence-based
Mike:	What?	Information seeking	
Jean:	Then you're changing the size of the cup.	Challenging	Test Procedure
Janice:	Did you put a different type of soil in?	Information seeking	
Galen:	No.	Elaborating	
Helen:	One day I came in and I put a little bit of sand. We just put a little bit.	Elaborating	
Aaron	But that's changing another variable.	Challenging	Test procedure
Adam:	Their test was a big phony. (Observation, 9/30/2010)	Rejecting	Simple

In this conversation, the students (Janice, Aaron, and Jean) were paying attention to evaluating the variables and the way they conducted the test. Although students played the role of critiquer to explicitly challenge Helen and Galen's presentation, the interaction in which students went back and forth with negative comments ("Their test was a big phony") did not resolve their problem and until the teacher intervened in their conversation when he said "Ok. I think we have 2 parties at fault here…" no meaningful consensus was reached.

Another trend in the beginning of the semester was that students spent a majority of their time challenging the accuracy of a claim, like "you still think they need sunlight or darkness?" (Observation, 10/4/2010), and "I don't get your claim. Do seeds need correct temperature or warmth?" (Observation, 10/8/2010). Those questions were common in the beginning of the semester. Students appeared to attempt to acquire surface declarative knowledge (Biggs, 1999), rather than understanding how and why they arrived at a claim. The reason students focused on the accuracy of a claim seemed to be due to the students' lack of familiarity with scientific arguments which often resulted in difficulties in challenging an explanation of evidence. These students, coming from a lecture classroom in which they had few opportunities to generate and evaluate evidence and reasoning, focused on gaining the simple result of experiments, rather than attempting to interpret evidence. Olivia indicated this point through her comments: “Last year, we did our experiments - like where we're gonna put it and stuff like that, but we didn't do anything else, really. We looked in a book and we just followed those rules. We didn't talk” (Olivia interview, 9/22/2010).

As a result, the purpose of challenging made by students in the beginning of the semester was to understand the procedure they used to conduct tests and to know whether their claims were correct from scientific books or textbooks, rather than justifying the reasons behind a claim. Although to a certain degree they did challenge each other, the conversation occurring in the beginning of the semester limited their knowledge construction to surface level ideas.

The structure of an argument. These data indicate that the dimension of challenging contributed by students in the middle of semester shifted to the connection between claims and question and the connection between claims and evidence. As illustrated in Figure 4.2, the frequency and proportion of the relationship between claim and question in the first round of the second unit increased to 12 and 11%. The frequency and proportion of the connection between claim and evidence was increased to 13 and 12 %. Instead of challenging the validity of a test procedure or whether a claim was correct, students were paying more attention to whether a claim answered the question they generated before the test as well as to whether evidence supported a claim. To illustrate this trend, consider the following example (see Table 4.5).

Table 4.5 Excerpt Illustrating Student Discourse in the First-round Negotiation of the Second Unit

	Classroom Discussion	**Coding**	**Sub-Coding**
Jaden:	Our claim is food goes through steps to allow your body to absorb energy from food.	(Presenting)	
Luke:	The parts of the digestive system are made of organs. Each step of the digestive system breaks down the food you eat. The steps of the digestions are...The food that no longer has nutrients is turned into waste and goes out the exit.	(Presenting)	
Kurt:	Your evidence supports your claim, but your claim doesn't relate to the big idea. The claim is food goes through the steps to allow your body to absorb energy from food. The big idea is human body systems work together. Your claim has nothing to do with human body systems.	Challenging	Claim-Question
Sara:	Yeah.	Supporting	Simple
Jake:	What if they changed it to food goes through steps through the digestive system.	Defending	Evidence-based
Kurt:	Then it would support the big idea.	Supporting	Simple
Nolan:	I don't think your evidence supported your claim. Because the focus of their claim is food's broken down and energy is absorbed. Are you showing how you know that food has energy and it's absorbed into the body?	Challenging	Claim-Evidence
Jaden:	First the teeth chew up the food, the tongue pushes the food up to the teeth, the saliva breaks down the food even more...and then the food goes into the small intestine. You...	Defending	Evidence-based
Luke:	Absorb the nutrients in the food. The food that…	Defending	Evidence
Nolan:	Well…Your evidence is missing how food's broken down? (Observation, 11/29/2010)	Challenging	Claim-Evidence

This excerpt was representative of the challenging patterns that took place after students participated in more rounds of negotiation. Students were likely to evaluate one another's ideas based upon the structure of argument, which consisted of question, claim, and evidence (Hand, 2008). In addition, the disagreements were resolved and these students were willing to revise their original arguments through these oppositional dialogues, which did not cause students to opt out of the discussion. For the final discussion, Jaden accepted his peers' suggestion and said, "we should change the claim and the evidence to make sense." Kurt illustrated the improved understanding of the importance of linking question, claims, and evidence as stated below,

> If the evidence has nothing to do with the topic, if the evidence has nothing to do with the claim, then I don't think that's very good evidence. And I think a good claim would be something that really relates to the big idea and is answering the big question. (Kurt interview, 11/30/2010)

As a result, students appeared to realize the argument structure much more and to understand how to justify a claim with evidence and reasoning specifically related to the claim.

The quality of evidence. The data indicate that the focusing dimension of challenging utterances contributed by students in the end of the semester shifted to the quality of evidence, as shown in Figure 4.2. The frequency and proportion of students' utterances in challenging the quality of evidence in the second round of the second unit were substantially increased to 77 and 54%. As noted in the field notes summary, "Students apparently developed a better understanding of the nature and quality of evidence based upon observing the explicit questions focused on the sufficiency and the appropriateness of the evidence and reasoning" (Field notes summary, 12/14/2010). To illustrate this trend, consider the following excerpt from the second round negotiation of the second unit (see Table 4.6).

Table 4.6 Excerpt Illustrating Student Discourse in the Second-Round Negotiation of the Second Unit

	Classroom Discussion	Coding	Sub-coding
Sara:	Our claim is some systems help air get in and out of your body.	(Presenting)	
Blair:	Our evidence is the systems that help get air in and out of our body are bones and muscles. The muscles help because the muscles pull down the diaphragm to get air into the lungs and the muscles also push out the diaphragm to get the air out of your body. The bones help because they hold the muscles and joints in place.	(Presenting)	
Megan:	Do the muscles and the bones help do anything to help air get in and out of your body?	Challenging	Evidence
Blair:	Yeah. The muscles help because like…	Defending	Evidence -based
Megan:	Ok, so what are those muscles? No, I mean, I know muscles help, but what are the muscles that have bones in them that still help?	Challenging	Evidence
Lucy:	And you said bones, but my arm doesn't help. My arm has a bone in it - my arm doesn't help me get air in or out.	Challenging	Evidence
Megan:	We don't know what bones you're talking about or muscles you're talking about that have bones that help you. Because as far as we know, the diaphragm doesn't have a bone…	Challenging	Evidence
Blair:	We could change that because like, the bones…	Defending	Evidence -based
Mike:	Where do you get this? Well, I mean, how do you know this evidence?	Challenging	Evidence
Jean:	Well, we know the diaphragm and the muscles around it from the test.	Defending	Simple
Kurt:	Can you explain how you got that from your test?	Information Seeking	
Jake:	Yeah, we know it from our test. Does that explain your reasoning and how you arrived at this answer?	Challenging	Evidence
Blair:	Well, we know it from like, our experiences…	Elaborating	
Jake:	You said the same thing again. How do you know that there are actually muscles and bones that work with the respiratory system?	Challenging	Evidence
Megan:	Yeah, in the beginning, you say it helps air get in and out of your body. You don't really talk about that. Your evidence doesn't help us. It just says the diaphragm helps to get air in and out of your body. That doesn't tell us how. (Observation, 12/15/2010)	Challenging	Evidence

During this conversation, this pattern of constantly asking questions about the quality of evidence is clear. After Sarah and Blair presented their claim and evidence, Megan's questions were focused on the appropriateness of the evidence and reasoning and asked for more detailed explanation of the evidence. Other students, like Lucy, Mike, Jean, and Kurt also followed Megan's question to critique this group's presentation based on the criteria of the sufficiency of reasoning. These data suggest that students developed a sophisticated understanding and criteria of what counts as good evidence, explanation, and reasoning after they engaged in more negotiation.

In addition, Lucy also presented a rebuttal (my arm doesn't help me get air in or out) to challenge Blair's argument. Based on the challenging questions made by students, they appeared to understand that an argument needs to contain claims and reasons for opposing points of view, and a choice between them, based on evaluation and confutation of the stand not taken. Much evidence emerged in this study to support this claim. Mike said:

> Now I understand that only providing one data wouldn't be that good of evidence because it wouldn't really get much stuff to know. You actually have to have reasoning, I think, to actually explain how it happened. That explains everything in the claim. (Mike interview, 12/13/2010)

As a result, the dimension of challenging is focused on the appropriateness and sufficiency of the evidence and reasoning, which are critical elements of argument (McNeill, Lizotte, Krajcik, & Marx, 2006; Sandoval & Millwood, 2005).

These analyses demonstrated that students were more willing to challenge or critique ideas over time when others proposed them. Students' foci of the challenging dimension distinctly shifted from the surface knowledge claims to the structure of the argument and the quality of evidence and reasoning. Criteria of evaluating evidence were also developed through students' negotiated practice. The results confirmed those from other studies on scientific argumentation that suggest that this ability to understand the structure of argument and the quality of evidence does not come naturally to most individuals (Osborne, Erduran, & Simon, 2004; Schwarz, 2009) but rather is grown through practice (Martin & Hand, 2009).

Theme 3: Over time, students came to use evidence to defend, support, and reject others' arguments in public negotiation processes.

In addition to the challenging component, considered one critical component of justifying or evaluating an argument in this study, data analyses based on the constant comparative method identified defending, supporting, and rejecting as three other critical components for argumentative processes. These data indicated that these students developed a better understanding of adopting and using more evidence to defend, support, and reject an argument after they participated in more rounds of negotiations, as shown in Figures 4.3, 4.4, and 4.5. The data revealed that the proportion of utterances made by students using evidence to defend, support, and reject an argument were 13%, 0%, and 0% in the first-round negotiation of the first unit. In the second round of the second unit, in contrast, the proportion of students who relied on evidence to defend, support, and reject was substantially increased to 88%, 74%, and 59%.

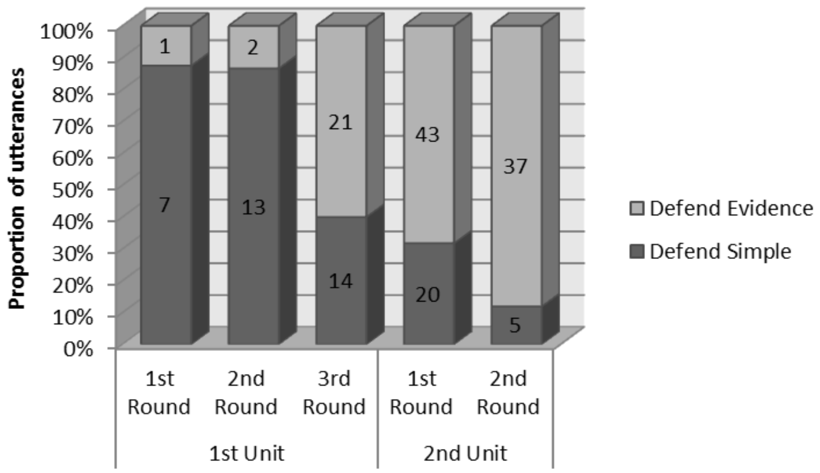


Figure 4.3 Frequency, Proportion, and Types of Defending Utterances Contributed by Students over Five Rounds of Negotiations

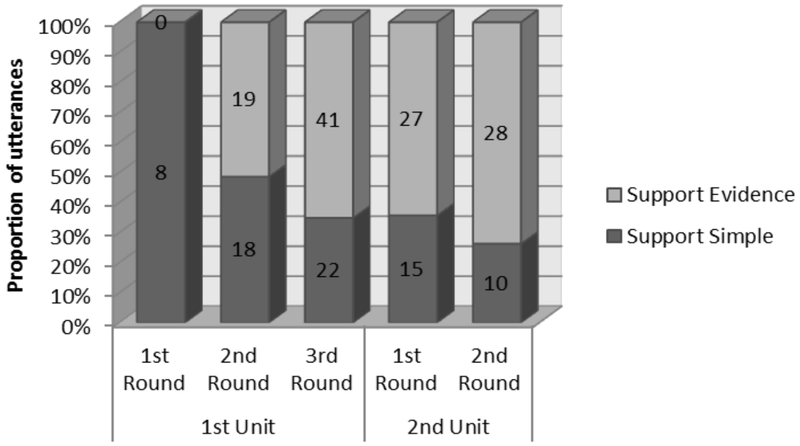


Figure 4.4 Frequency, Proportion, and Types of Supporting Utterances Contributed by Students over Five Rounds of Negotiations

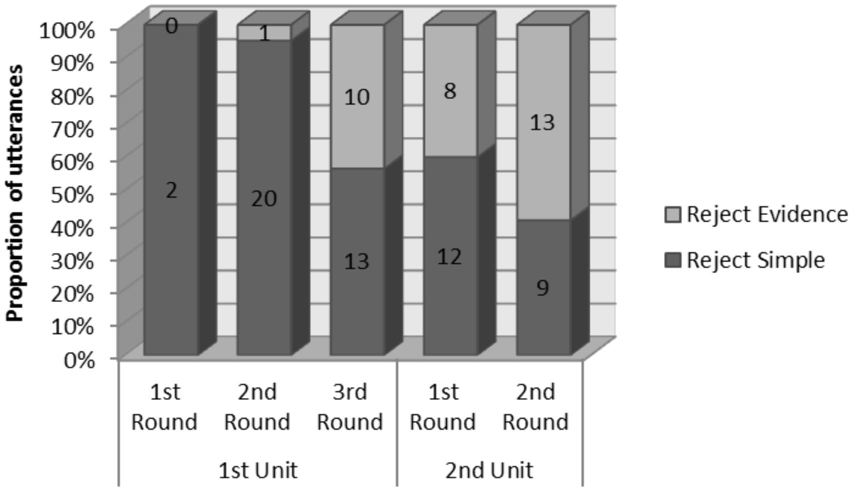


Figure 4.5 Frequency, Proportion, and Types of Rejecting Utterances Contributed by Students over Five Rounds of Negotiations

To illustrate this trend, consider the following example in the second round negotiation of the first unit. Students were discussing whether sunlight or darkness is necessary for seeds to germinate. Some students believed that seeds need sunlight or darkness to germinate, but some students simply rejected the idea, such as in the utterances, “We don't believe that they need sunlight or darkness,” and “You can put it anywhere.” Students like Aaron supported the latter idea, saying “Yeah, it's not a requirement.” However, students who believed seeds need sunlight or darkness to germinate defended their idea, such as “But some plants do,” “They need sunlight,” and “I learned in kindergarten that it needs sun to germinate.” The pattern of the discussion students contributed was simply expressing and rejecting the merit of ideas based on their personal inferences, intuition, and past experience without supporting evidence. Ryan expressed his viewpoint of this kind of conversation after this class, “If that person still thinks there's someone, they say it all again. They just keep repeating the same idea. We're not getting anywhere. It gets boring after awhile” (Ryan interview, 10/4/2010). Consequently, students’ discussion without evidence and reasoning support was limited and ineffective in terms of the content knowledge for that topic.

However, these students, after engaging in more rounds of negotiations, apparently developed a better understanding of using evidence to defend, support, and reject an argument proposed by others. The following examples nicely capture that students were attempting to use evidence to evaluate and express an argument when they were discussing the function of the respiratory system in the second round of the second unit (see Table 4.7).

Table 4.7 Excerpt Illustrating Student Discourse in the Second-round Negotiation of the Second Unit

	Classroom Discussion	Coding	Sub-Coding
Ryan:	It's more about your claim - how does it [respiratory system] use the muscular system?	Challenging	Claim-Evidence
Nolan:	The lungs need to expand when you breathe in, so the diaphragm pushes like, the stomach down and kind of squishes it so the lungs have room to expand like that. And then, when they get full of air [he is drawing his model under a projector, see Figure 4.6].	Defending	Evidence-based
Janice:	The diaphragm doesn't move the lungs; it doesn't touch them. You can't move your lungs - they're stable.	Rejecting	Evidence-based
Andrea:	Yeah. On this model [she is showing his simulated model about how the lungs work with the diaphragm], it doesn't have to move it. When the diaphragm goes down, it gives it more space and it pulls the pressure down. And when the diaphragm goes up…(Observation, 12/15/2010)	Supporting	Evidence-based

Unlike the beginning of the semester, these students were more likely to rely on evidence to defend (Nolan), reject (Janice), and support (Andrea) an argument and how well the argument fits with their thinking based on scientific reasoning. Students came to be more aware of the importance of using evidence to support their own ideas, rather than just expressing their ideas without any reasoning. For example, Blair recognized the importance of adopting evidence in the argumentative process, “The most important part [of argumentation] I want to hear in other people's thing is their evidence. If you don't support your idea by using evidence, then we're not going to know anything about the idea and why you said that” (Blair interview, 1/13/2011).

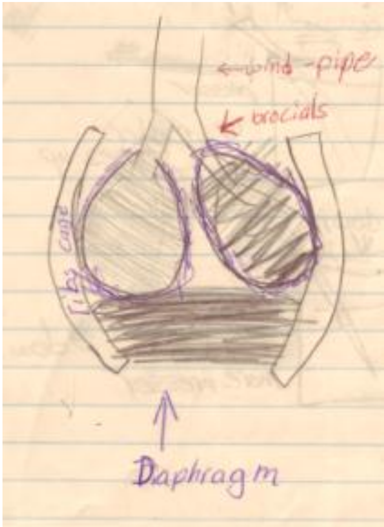


Figure 4.6 Nolan's Sketch Representing His Image of the Respiratory System

This trend of adopting evidence in public negotiation resulted in two characteristics: (1) students were more willing to accept other arguments or shift their original ideas, and (2) the discussion was more effective in terms of reinforcing core concepts about that topic. Much evidence emerged from students' interviews in this study to support this assertion.

Willing to shift original argument. As shown in Table 4.6, Nolan defended his argument by drawing a graph (shown in Figure 4.6) to visualize his model and explain it, rather than insisting upon his idea without providing solid evidence to support it. Because of this, Janice and Andrea obtained a clearer understanding of Nolan's model of the respiratory system and why Nolan thought the diaphragm "squishes" or expands the lungs to make air move in and out. In response to Nolan's visualized model, Janice and Andrea provided a simulated model and included more evidence to express their disagreement. For the rest of the discussion, students continuously made a judgment or explanation in terms of providing their evidence and explanation, like "it [diaphragm] doesn't have to touch it and it still moves. When the diaphragm goes down, it gives it more space and it pulls the pressure down." Consequently, Nolan was persuaded by his peers' evidence-based talk and accepted the argument proposed by Andrea. Nolan said, “Andrea made a good example and explanation when she showed us that model, because that model shows the diaphragm does not even come close to touching the lung and how the lungs work, I agree with that now” (Field notes summary, 12/15/2010).

This example nicely captures the condition in which students were more likely to accept other arguments if they used evidence to express and evaluate an argument. Not only did students rely on talk to persuade others of their ideas, they also used writing and other model representations to express their ideas more explicitly. This claim was further elucidated here by Olivia, “If you agree or disagree, you can't just say, ‘I agree’ and expect them to just believe you. You have to say why you disagree or why you agree…drawing a picture is a good way to explain my idea” (Olivia interview, 11/30/2010).

Effective dialogue. After students engaged in more rounds of negotiation, they came to be more aware of the usefulness of providing evidence to support their ideas during defending, supporting, and rejecting ideas proposed by others. Mike pointed out that adopting evidence to support an idea made their discussion more effective. He said:

> Now we kind of understand what we need in order to judge a poster, so now we got through posters really fast and we started on something else. We have to provide evidence to support our claim to negotiate. Not like the other days [beginning of the semester] where we just go in circles and circles and circles about an idea. We didn’t go anywhere. (Mike interview, 11/5/2010)

Similarly, Ryan reflected on the whole negotiated process at the end of the semester and perceived that the students developed good skills to defend their ideas, which extended their discussion to a deeper level; he said:

> The beginning of the year, we weren't really talking then we fell behind, and I'm guessing it's probably because of us going, "Okay, we'll change that." We didn't go all on defense mode…You're not being really good. They're trying to tell you to do something and trying to make a conversation-type thing with you, and you're just dropping down your side of the conversation, going, "Okay." Now I think our thinking has changed a lot. If you came up with this claim and evidence,

> why don't you support it? So I think the most important part is supporting it with evidence. (Ryan interview, 1/13/2011)

In addition to defending ideas with evidence, students also came to understand the usefulness of using evidence to reject and support an argument in order to deepen and clarify their ideas. Blair said:

> I think our class discussions in the past have been not that good because usually we'd be like, "Well, I disagree with this. That person would go, 'Okay.'" We don't know why the person agreed or disagreed. But I think our class discussion was good now. You have to say why you agree or disagree to them. The person that's telling the comment has to say why they agree or disagree with you. I have a more clear idea after negotiation… I think negotiation is when you listen to all the ideas and you don't say, "Oh, well that's so mean!" and stuff like that, or raise a bad voice at them…You can just go, "Yeah, I agree with yours because..." and stuff like that. (Blair interview, 12/1/2010)

Overall, students were aware of the importance and usefulness of using evidence for their defense, rejection, and support in pubic negotiation processes. The analysis also points toward the conclusion that students developed good skills to resolve disagreements in the later rounds of negotiation as well as to revise their original arguments through these evidence-based discussions. To further elaborate this finding, students were able and willing to co-construct scientific knowledge in public negotiations in terms of providing evidence by using talk and writing to persuade their audience of their ideas and make sense of others' ideas. Consequently, their discussion became more effective than it was at the beginning of the semester.

Theme 4: Over time, students, both initially talkative and quiet students, came to implement argument components in public negotiation processes.

The previous three themes examined the use of argumentation components in a whole class setting over the course of one semester. However, one question might be raised: did all students come to use argumentation components in public negotiations? Or did just a number of students improve their abilities to use the components identified in this study? In addition, some researchers have indicated that some groups, like quiet students who are less confident or less articulate, might be negatively impacted by their lack of involvement in the whole class approach to argumentation (Venville & Dawson, 2010). In light of these questions, this theme will focus on whether both initially talkative and quiet students increased their use of argumentation components in negotiations over time. Six students, including initially talkative and quiet students, were purposefully selected to answer this question.

Figure 4.7 shows the trend in the use of argumentation components by the six students over five rounds of negotiation. These data reveal that both groups gradually adopted argumentation components over time. In terms of initially talkative students, Kurt is a good example. Kurt increased his use of argumentation components from 12 times in the first round of the first unit to 31 times in the second round of the second unit. Some essential components, like elaborating, challenging, defending, rejecting, and supporting also increased over time. This pattern held true for Olivia and Nolan as well.

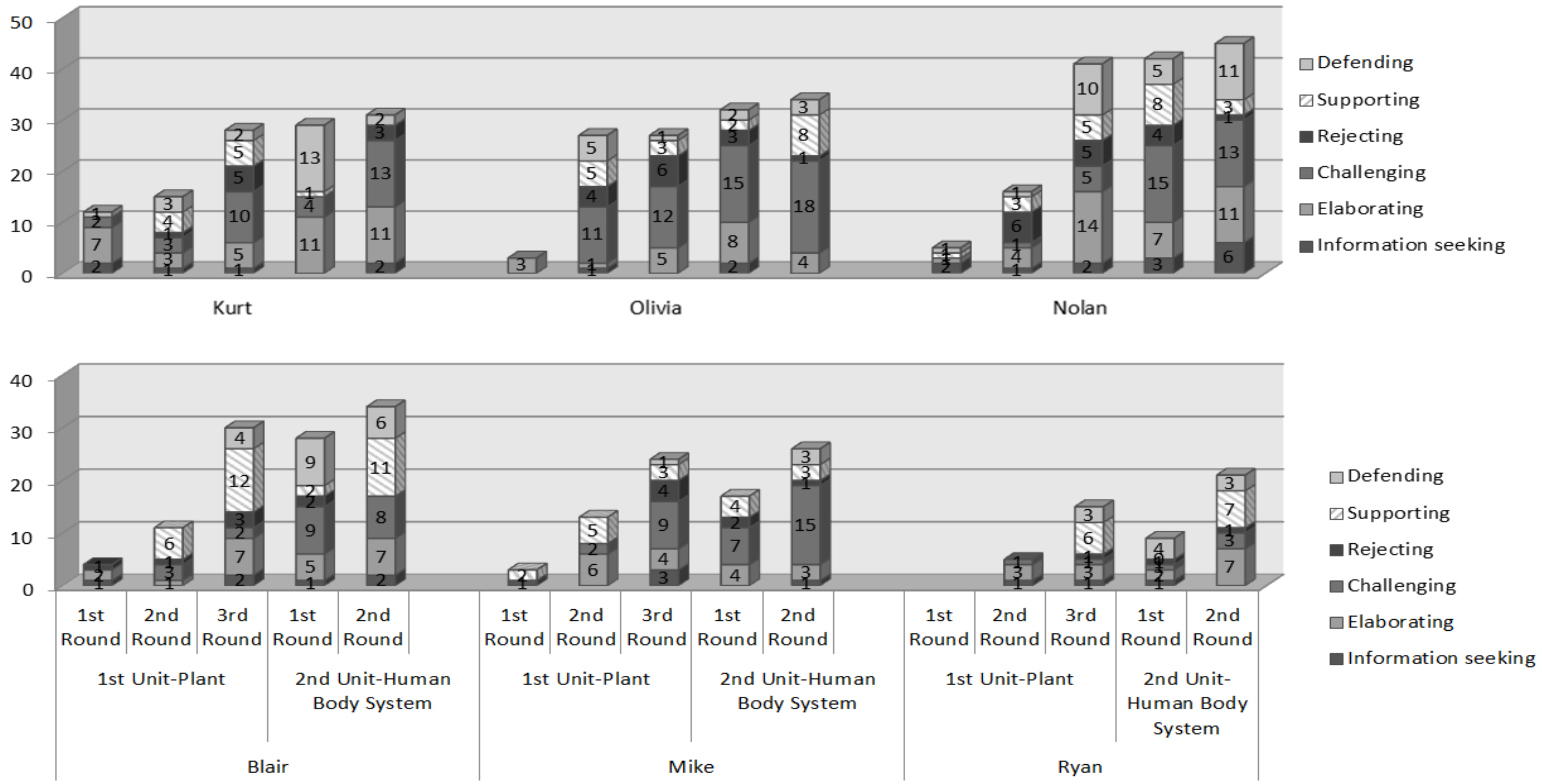


Figure 4.7 The Trend in the Use of Argumentation Components by Initially Talkative and Quiet Students over Time

Initially quiet students showed the same trend as talkative students. Consider Ryan as an example. He talked least in the quiet group and did not use any argumentation components in the first round of the first unit, but he used 21 argumentation components in the second round of the second unit.

Additionally, one interesting point, shown in Figure 4.7, is that the number of argumentation components used by initially quiet students decreased slightly from unit one to unit two. However, all of them included more argumentative responses in the second round of the second unit than in last round of the first unit. This result represents a substantial shift in the use of argumentation components by both initially talkative and quiet students over time.

Thus far, this chapter has discussed the development of students' understanding of the nature of argumentation components when they participated in public negotiations. The next section demonstrates students' improved ability of crafting written arguments to answer part of the first research question.

Finding Two: Increased Quality of Crafting Written Arguments

To examine how students developed the quality of written arguments over time, their written arguments were analyzed in terms of five essential components including: accuracy of a claim, sufficiency and reasoning of evidence, relationship between a claim and question, and relationship between a claim and evidence. The results suggest that students' scores on those argument components increased over time. Students' interview and field notes revealed that the improved quality of written arguments was closely related to the participation in argumentative practice and the awareness of the usefulness and importance of feedback. At the end of this section, the relationship between talk and writing will be discussed in detail.

Theme 5: Over time, the quality of students' writing improved and tended toward argument-based approaches.

To explore whether students' ability to craft a written scientific argument was improved after they were provided with more rounds of writing practice, students' written arguments in each group were scored based upon the argument-based rubric, as shown in Table 3.15. Five scales were designed to evaluate students' group written arguments for the five essential components of accuracy of a claim, sufficiency and reasoning of evidence, relationship between a claim and question, and relationship between a claim and evidence. Figure 4.8 charts the average score for the five argument-based written components identified in this study, respectively. Table 4.8 shows the average and total score for each written component. In the first unit, the total score for scientific written arguments in the first round was 2.86 (out of 20 possible points). The total score dramatically increased to 15 in the fourth round. In the second unit, the total score in the first round was 11.67. The total score increased to 19 in the third round. In addition, students' written scores for each component increased in each unit. This analysis indicates that these students were able to craft higher quality and more sophisticated arguments when they had more opportunities to practice scientific written arguments.

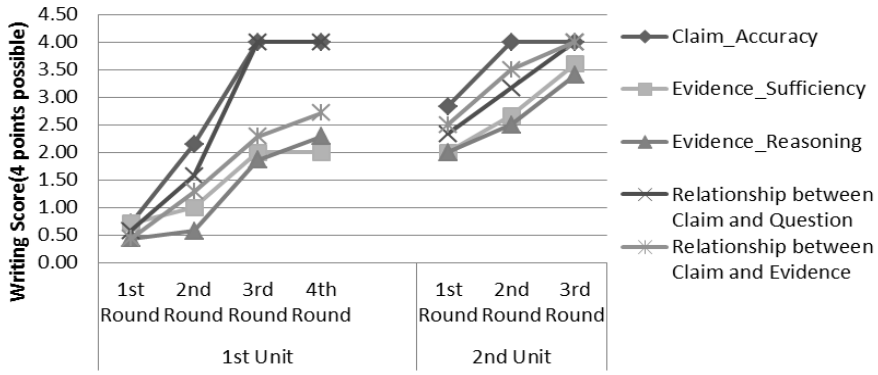


Figure 4.8 The Average Score for Written Scientific Arguments on Each Component over Two Units

Table 4.8 Total And Average Scores for Scientific Written Arguments on Each Component over Two Units

Unit/ Round / Writing Component	1st Unit				2nd Unit		
	1st Round (7 groups)	2nd Round (7 groups)	3rd Round (7 groups)	4th Round (7 groups)	1st Round (6 groups)	2nd Round (6 groups)	3rd Round (6 groups)
Claim _ accuracy	0.71	2.14	4.00	4.00	2.83	4.00	4.00
Evidence _ sufficiency	0.71	1.00	2.00	2.00	2.00	2.67	3.60
Evidence _ reasoning	0.43	0.57	1.86	2.29	2.00	2.50	3.40
Relationship between Claim and Question	0.57	1.57	4.00	4.00	2.33	3.17	4.00
Relationship between Claim and Evidence	0.43	1.29	2.29	2.71	2.50	3.50	4.00
Total score	2.86	6.57	14.14	15.00	11.67	15.83	19.00

To illustrate this trend, consider the following written argument, produced by Nolan's group. This writing sample exemplifies the type of argument crafted by the students working in small groups at the beginning of the semester.

> Claim: A plant needs air and water to grow.
>
> Evidence: If a plant doesn't have air, it cannot grow. If you give a plant with more water, it'll grow faster than it would not. The more air you give a plant, the faster it will grow. (Nolan's group writing sample, 9/29/2010)

This argument is an attempt to answer the research question: what is needed for seeds to germinate. It includes a claim and evidence. However, their argument focused on what is needed for a *plant* to grow, rather than for *seeds* to germinate. In this regard, the claim did not answer the research question (0 out of 4 points) although the claim is partially correct (1 out of 4 points) in terms of scientific concepts. In addition, this group included only one set of data in their evidence and no reasoning to support their claim. They simply rephrased their claim in the evidence and did not make an appropriate or adequate explanation based on the interpretation of the investigation data. Hence, the sufficiency of evidence and the relationship between claim and evidence was scored as limited (1 out of 4) and the reasoning of evidence was scored as lacking (0 out of 4). Nevertheless, this group produced a better argument in the fourth round:

> Claim: Seeds need air, water, correct temperature, and energy to germinate.
>
> Evidence: A seed need air to germinate because if it doesn't have this it would suffocate. I know it will suffocate because in the test I put seeds in two bags. One bag was full of air, the other was not. In the bag that did not have any air the seeds didn't germinate at all. In the bag that had air in it the seeds germinates a bit. This is how I know that a seed needs air to germinate.
>
> A seed needs water to germinate or it will get dehydrated and die. Not only will a seed get dehydrated but it will also not be able to crack open. A seed needs to crack open so it can let its roots and the sprout come out so it can germinate. I know the seed crack open because in a previous grade I watched a video. In the video it shows the seeds taking in the water, filling up and cracking open so the roots can come out.
>
> If a seed has too much water, it won't germinate because the seed will drown. Even if it didn't drown (this is kind of what drowning means), the water on top would fill up all the pore spaces in the soil and the seed would suffocate. I know this because in a test, the group had a lot of water (250ml) in one cup, some water in another (30ml) and no water. The seeds in the cup with a lot of water and the one with no water did not germinate.
>
> A seed needs the correct temperature or it will freeze or it will get too warm and die. I know that a seed could freeze and it could not germinate because in a test, the group put a seed in a freezer and it didn't germinate. If it is too hot, the seed would survive and die.
>
> A seed needs energy because it has energy (nutrient) in it. But it can run out and then it would need it to finish germination. (Nolan's group writing sample, 10/22/2010)

This argument, apparently, was improved after students had more opportunities to revise their thinking in light of the negotiations. Their claim was scientifically correct and targeted to answer the research question. Thus, the accuracy of the claim and the relationship between the claim and question were scored as exemplary (4 out of 4 points). The students also made a strong and sophisticated connection between claim and evidence in which they put relevant and appropriate evidence together to explain why seeds need air, water, the correct temperature, and energy. The relationship between claim and evidence was scored as exemplary (4 out of 4 points). This group then included multiple datasets and reasoning in the evidence; they also used counterevidence to support their argument that water and the correct temperature were necessary for seeds to germinate. However, they did not include enough data and reasons to support their claim that nutrients are a critical resource for germination. Therefore, the sufficiency and reasoning of evidence were scored as proficient (3 out of 4 points). Overall, the two examples show that the quality of the students' written scientific arguments was improved in terms of building the connections between elements of arguments (question, claim, and evidence) and the complexity of the evidence after more opportunities to revise their arguments.

This improvement in the quality of argument seemed to be due, in large part, to two factors: (1) engagement in scientific writing embedded with argumentative practice, and (2) an awareness of the usefulness of feedback from peers.

Scientific writing practice embedded in argumentative practice. This improvement in the quality of written argument does not result from learning the structure and components of argument first and then applying the knowledge in the written arguments (Hand, 2008). Rather, students developed a better understanding of the argument structure and components within the argumentative context of creating arguments about topics. Consider the earlier written example by Nolan. In the first round of writing practice, Nolan only included the data in the evidence without any reasoning or judgment ("If a plant doesn't have air, it cannot grow."). Although he was taught the genre of argument structure at the beginning of the semester, it was still very abstract to him. He pointed out that "I knew evidence would be something to support the claim or help people better understand it", but "evidence is really hard to make" (Nolan interview, 10/1/2010).

However, after engaging in the investigation embedded with argumentative practice, he seemed to develop a more sophisticated understanding of the structure of argument. His understanding is reflected in his writing sample in the fourth round of the first unit. Nolan's statement nicely captures his understanding of the structure of argument, "evidence gonna be like, explaining how our test went and why it was the one with the most air grew the fastest, and the one without air didn't grow at all, and carbon dioxide doesn't grow very fast. You have to reason" (Nolan interview, 11/23/2010). He further distinguished the difference between data and evidence after practice with more argumentative writing, "Data is like what happened in the test. You actually have to have reasoning, I think, to actually explain how it happened" (Nolan interview, 11/30/2010).

These examples suggest that students developed a better understanding of what counts as claims, evidence, and data after participating in argumentative processes. Nolan elucidated the change; "After I have more experience [argumentative practice], I know how to write good claim and evidence" (Nolan interview, 11/23/2010).

The students' increased abilities to craft written arguments were closely related to their participation in argumentative practice. This claim could be explained by Figures 4.1- 4.5 and 4.7. In Figures 4.1 and 4.2, the results display that students developed a more sophisticated understanding of argumentation components. In addition, the foci of the challenging dimension were shifted from the accuracy of claims to the argument structure and the quality of evidence. Figure 4.7 shows that students writing arguments improved in the accuracy of the claim first, then in the relationship between question, claim and evidence, and finally in the quality of evidence. The three figures indicate that the dimensions of students' improved abilities of crafting a written argument paralleled the use and foci of challenging dimensions. In addition, Figures 4.3- 4.5 show that students used more evidence to defend, support, and reject an argument, which also aligned with the improved quality of students' written arguments over time. Building on argument, talk and writing thus appear to be interdependent skills.

Overall, the results indicate that students' improved understanding of argument structure and the quality of components resulted from engaging in argumentative practice. The processes of learning to argue and arguing to learn cannot be separated. By embedding science argumentation in scientific inquiry, students are able to build an understanding of the necessary processes for constructing a scientific argument (Clark & Sampson, 2008; Keys, Hand, Prain, & Collins, 1999; Sandoval & Millwood, 2005). The understanding then becomes part of their reasoning process and they are able to write and answer questions that involve argument.

Awareness of the usefulness of feedback. Another aspect of the written arguments that students considered beneficial was feedback from their peers. Take the written argument of Nolan's group as an example. After Nolan and his group members presented their claim and evidence in the first round of negotiation, other students provided feedback such as, "You may need to explain why seeds need water to germinate," and " Your evidence just repeats your claim again" (Observation, 10/4/2010). Nolan perceived the usefulness of this feedback and stated:

> I think our evidence is too simple. Janice said she cannot get our claim and evidence. I think I gonna explain how our test went, not just saying that a seed would need water but saying why, or how it could have too much. (Nolan interview, 10/4/2010)

Nolan's remarks provide an example of how the negotiated processes scaffolded him to develop and craft a high quality written argument. Blair also saw the value of feedback on her written argument, which she said helped her learn better:

> Once we shared it, I realized that we had to make a lot of fixes to it. Everybody made comments, we decided that we should discuss more about the big idea…because they were explaining to us which parts were bad and which parts were not. I feel I learn more… (Blair interview, 11/23/2010)

Ryan also provided his view of feedback, "I like to write something before talk, and come back to write and then talk again. This helped me to know what I have to improve on my writing and we don't have to waste time talking in the class" (Ryan interview, 12/13/2010).

These examples reveal that the negotiated processes facilitated an improvement in writing quality. Writing also advanced the quality of talk, which would suggest that talk and writing are dependent upon each other. However, not all feedback was considered useful by students; for example, "Some of them [feedback] were good, could have gotten us ahead on the topic. Some of them were just repeating them, or just weird" (Mike interview, 11/22/2010). Mike further explained that "If they explain very well and tell me my problem, then you agree with them" (Mike interview, 11/22/2010), otherwise "some of their feedback was not that important because they do not say the reason" (Olivia interview, 01/13/2011). These statements from students' interviews indicate that feedback related to the problem or solution or understanding and reasoning lead to feedback implementation. This finding is consistent with Theme 3. What makes students shift or improve their ideas is the use of evidence-based feedback, based on the criteria of defending, supporting, and rejecting.

In sum, the data analysis suggests that the overall quality of the written arguments and the understanding of argument structure and components were improved when students were provided with more opportunities to craft their writing. The improvement of written arguments and understanding was the result of engagement in scientific writing embedded within argumentative practice and an awareness of the usefulness of feedback.

Taking the results from Finding One and Finding Two together, the quality of writing, to some degree, was dependent on the way students participated in the argumentative practice, and vice versa. In other words, talk and writing would appear to be interdependent. Building on these results, the next section will examine how talk and writing interact with each other and how the different interactions support student knowledge construction.

Finding Three: Five patterns of the use of talk and writing for knowledge construction and cognitive processes were identified

The second research question of this study was: In what ways do talk and writing support students' scientific knowledge construction in an argument-based inquiry classroom? To answer this question, an in-depth analysis of Knowledge Construct Trajectory (KCT) episodes was conducted. Three themes emerged from this analysis. First, when talk and writing were used in combination, student knowledge construction occurred more than when only one learning tool was used. Second, when talk and writing were used in sequence or simultaneously, students' higher cognitive processes were provided more scaffolding than when talk and writing were used alone. Third, while the use of talk and writing separately was more teacher-directed, the use of talk and writing simultaneously was more student-directed.

These results provide insights into how educators and researchers could exploit the potential use of the combination of talk and writing in order to encourage students to construct scientific knowledge at higher cognitive levels.

Theme 6: When talk and writing were used in combination, student knowledge construction occurred more than when only one learning tool was used.

An in-depth analysis of Knowledge Construction Trajectory (KCT) episodes showed how students built scientific knowledge using talk and/or writing in an argument-based inquiry classroom during two units, shown in Appendix E. As a result of the analysis, twenty-one KCT episodes were identified in which students' knowledge construction was recognized (see Table 4.9). Five patterns across the KCT episodes in terms of the use of talk and writing were identified: (1) talk only (e.g. Blair, episode 1), (2) writing only (e.g. Kurt, episode 1), (3) use of talk and writing in sequence (e.g. Kurt, episode 2), (4) use of talk and writing simultaneously (e.g. Blair, episode 6), and (5) a combination of sequence and simultaneity (e.g. Nolan, episode 2).

Table 4.9 Five Examples for Five Patterns

Pattern 1: Talk Only (Blair, episode 1)	Pattern 2: Writing Only (Kurt, Episode 1)
Event 1: A small group test Do seeds need sunlight or darkness to germinate? ↓ ***Event 2: A whole class discussion*** Seeds need sunlight and/ or darkness to germinate	***Event 1: A small group test*** What does a seed need to germinate? ↓ ***Event 2: A small group writing*** A plant needs water to germinate
Pattern 3: Use of Talk and Writing in Sequence (Kurt, episode 2)	**Pattern 4: Use of Talk and Writing Simultaneously (Blair, episode 6)**
Event 1: A small group writing A plant needs water to live ↓ ***Event 2: A Whole Class discussion*** A plant needs water, air, and soil to germinate ↓ ***Event 3: A small group writing*** A plant needs water, air, and soil to live	***Event 1: A whole class discussion and individual writing*** Digesting is a process that makes the food break down ↓ ***Event 2: A small group talk and writing*** The digestive system uses other systems of organs to work
Pattern 5: A Combination of Sequence and Simultaneity (Nolan, episode 2)	
Event 1: A whole class discussion and individual writing Seeds need air to germinate ↓ ***Event 2: A small group writing*** seeds need air, water and correct temperature to germinate	Talk only Writing Only Talk and Writing

Note: Broken line boxes indicate that the target students only used talk as learning in the event; solid line boxes indicate that the target students only used writing as a learning tool in the event; double line boxes indicate that students used both talk and writing as learning tools in the event.

To clarify the meaning of the five patterns, five examples are provided in Table 4.9. The first pattern identified as *talk only* indicates that the target student only used talk as the learning tool to construct the core concept in each event in the episode. The second pattern identified as *writing only* indicates that the target student only used writing as the learning tool to construct the core concept in each event in the episode. The third pattern identified as *use of talk and writing in sequence* indicates that the target student used different learning tools in each event, but the target student only used one learning tool in each event. The fourth pattern identified as *use of talk* *and writing simultaneously* indicates that the target student used two learning tools together in each event. The fifth pattern identified as *a combination of sequence and simultaneity* indicates the target students used one learning tool in one event, but use two learning tools together in another event.

The results from an in-depth analysis of KCT episodes indicated that when talk and writing were used in combination, students' knowledge construction was more supported than when only one learning tool was used. As summarized in Table 4.10, students used only one learning tool, either talk (Blair, episode 1) or writing (Kurt, episode 1), to build their understanding of the core concepts in two of the twenty-one observed episodes. These two episodes occurred at the beginning of the semester in which students were initially involved in argument-based inquiry contexts. With increasing opportunities to engage in argument-based inquiry, the students tended to use different combinations of talk and writing in activities to construct their understanding of the core concepts. The number of episodes in which students used talk and writing simultaneously increased from zero in the first unit to 7 in the second unit, whereas the frequency of talk and writing used sequentially or mixed together decreased from 4 and 5 to zero and 3.

In addition, as shown in Table 4.10, students' knowledge construction occurred more when talk and writing were used together (19 episodes) than when only one was used (2 episodes). To illustrate the characteristics of the five patterns and the changes in the use of talk and writing over time, what follows is a description of each pattern.

Table 4.10 Number of KCT Episodes Identified in Each Unit for Each Student

Topics	Students	Only Talk	Only Writing	Combination of Talk & Writing		
				Sequence	Combination of Sequence and Simultaneity	Simultaneity
Unit 1: Ecosystem	Kurt	0	1	1	2	0
	Blair	1	0	1	1	0
	Nolan	0	0	2	2	0
Sub Total		**1**	**1**	**4**	**5**	**0**
Unit 2: Human Body System	Kurt	0	0	0	1	2
	Blair	0	0	0	1	3
	Nolan	0	0	0	1	2
Sub Total		**0**	**0**	**0**	**3**	**7**
Total		**1**	**1**	**4**	**8**	**7**

Talk or writing alone. Kurt's KCT Episode 1, as shown in Figure 4.9, is an example of using writing alone to construct scientific knowledge. This episode consisted of two events. In Event 1, Kurt was randomly assigned to a group with Aaron to investigate what a seed needs to germinate. Kurt's group chose water as their investigation variable for the research question[5].

During the investigation, Kurt played the leading role in designing and conducting the experiment. He recorded the results by himself in his journal. Although Aaron participated and talked, Kurt rarely considered Aaron's ideas or discussed results with him (Field notes summary, 9/29/2010).

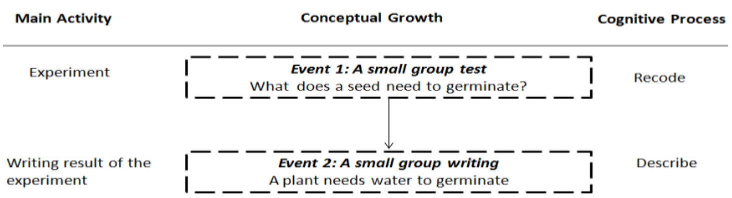


Figure 4.9 Kurt's Knowledge Construction Trajectory (KCT) Episode 1

5 In the beginning of the unit, students were discussing what variable may be necessary for seeds to germinate. Seven variables were generated from the students' discussion. Then, students were randomly assigned to seven groups by the teacher. Each group was able to choose one variable to investigate.

In an interview with Kurt about how he perceived the role of Aaron in the group, he stated, “I don't think he [Aaron] really helped,” but “he helped with some parts…When I was writing it back down on the poster he kind of stated what I wrote in my journal and then I wrote it down” (Kurt interview, 10/1/2010). Kurt rarely considered Aaron’s ideas and feedback, although Kurt was asked to participate in a group investigation. The use of talk to construct knowledge is difficult to see in this event. Kurt seemed to only use writing as a learning tool to “generate” knowledge. As shown in Figure 4.10, he also constrained his use of writing to recording the data and organizing the results, rather than analyzing or interpreting the data as evidence (Kurt writing sample, 9/20/2010). For example, during the investigation, Kurt described the procedure step by step and recorded the results. No analysis and interpretation of the data were observed from his writing.

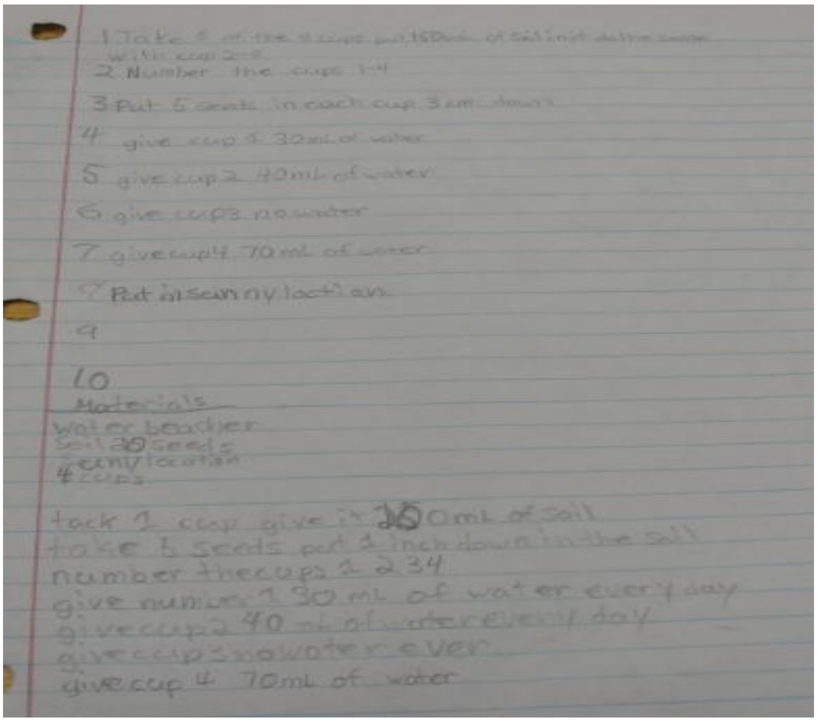


Figure 4.10 Kurt’s Writing Sample Collected during KCT Episode 1

In Event 2 of KCT Episode 1, Kurt summarized the group's claim and evidence as shown below.

> Claim: A plant needs water to live.
>
> Evidence: We figured out that for a seed to live, it needs water. Water's a part of its life. We tested them without water and found that our seeds will die. Also, if you give a plant too much water, it will drown. It needed about 30mL of water to germinate, grow. We even found out that 40 mL of water was a little too much. (Kurt group writing sample, 9/30/2010)

In this writing sample, Kurt simply repeated or rephrased the data that he got from the test without any explanation about why a seed needs water to germinate. In addition, his claim is about a plant, not a seed, even though he was asked to investigate what a seed needs to germinate and grow. The function of writing in this episode is "knowledge telling" (Bereiter & Scardamalia, 1987) which simply involves retrieving ideas prompted spontaneously by the topic and translating them directly into text. Kurt stated that the role of writing is to "understand what we were doing the last time" (Kurt interview, 9/30/2010). The process of writing was a purely individual cognitive approach focusing on retrieving ideas and making a written record of them.

This episode is not surprising. Individual writing is often the only language strategy that is used in many science classrooms (Rivard & Straw, 2000) even though students are often asked to work in small groups, especially in traditional classrooms. The students, particularly young students, usually consider writing to be the product-based approach of the investigation, rather than part of process or both (Galbraith & Rijlaarsdam, 1999).

Use of talk and writing in sequence. Blair's KCT Episode 3, shown in Figure 4.11, is an example of using talk and writing in sequence. This episode occurred when the students were discussing the food chain. In Event 1, after students constructed a concept map related to the ecosystem, the teacher asked the following question, "The human eats the cow, and the cow consumes the grass, and the grass gets energy from the sun. So do humans get their energy from the sun?" (Observation, 10/22/2010). Blair expressed her idea immediately, "We get part of our energy from sun, but also part from food." However, other students did not seem to completely agree. For example, Ryan said "If we do not have the sun, we have no food. We die." The following discussion represents the dialogue in Event 2 (see Table 4.11).

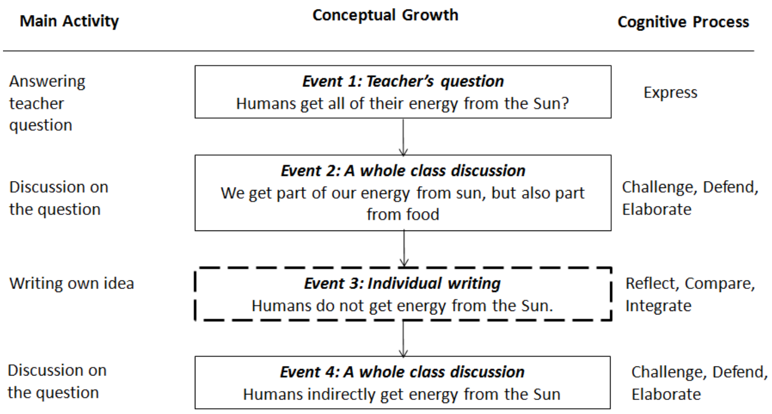


Figure 4.11 Blair's Knowledge Construction Trajectory (KCT) Episode 3

Table 4.11 Excerpt Illustrating Blair's Discussion in Event 2 of Episode 3

Whole Class Discussion		Codes	Sub-Codes
Blair:	I'm not saying we don't get our energy from the sun, but we get it also from food and the sun.	Elaborate	
Nolan:	But you wouldn't have food if you didn't have sun.	Challenge	
Blair:	My plants grew in darkness.	Challenge	
Teacher:	People eat bass (a fish), which eat grasshoppers, which eat grass, which gets energy from sunlight, so people get energy from the sun.	Support	Evidence-based
Megan:	No, grass gets energy from the sun. It doesn't go right to people. It is different parts, like humans go eat bass; it's not like we would eat grasshoppers, and we don't eat grass.	Reject	Evidence-based
Teacher:	I didn't say we get our energy from grasshoppers, I said we got it from the sun.	Elaborate	
Jake:	It goes through a process to get to you. (Observation, 10/21/2010)	Support	Simple

The discussions here appear to be disorganized and quite chaotic with diverse ideas and uncertain references. However, the discussions led Blair and other students to share, clarify, challenge, and defend their various answers to the question. Although the students did not achieve consensus, talk served as a catalyst for negotiating and refining their collective understanding. At the end of the class, the teacher asked them to write down their ideas about the question. Blair wrote down her response as follows:

> Our energy comes from food. I think that because the sun does not give it directly to us. It gives it to the food we eat which has energy produced inside it. I got this information from our discussion. We do need sunlight to live but that does not necessary mean that it gives us energy. Plants need energy from the sun to grow, but we do not. (Blair writing sample, 10/21/2010)

Blair's writing response after the discussion indicates that she slightly shifted her position from an initial idea that we get energy from food and the sun to the belief that our energy comes from food (although this is not consistent with scientific concepts). She appeared to reflect on the discussion and integrate her understanding with her peers' ideas. The role of writing, in this event, seemed to be particularly important for students to reflect and reorganize their ideas in a logical and coherent way after a rambling and divergent discussion.

In Event 4, the students came back to discuss the question. After they deliberated their ideas by writing in a journal, the "students were more focused on giving an explanation of their ideas, rather than just expressing their thoughts without any reasoning like in the previous class" (Field notes summary, 10/22/2010). Blair explained her idea based upon the writing she did with other students as follows (see Table 4.12).

Table 4.12 Excerpt Illustrating Blair's Discussion in Event 4 in Episode 3

	Whole Class Discussion	Code	Sub-Code
Blair:	I disagree because we eat food, but the sun has to go through the food to get to us, if we just stood there, we wouldn't basically be getting any energy from the sun. But when the sun goes into the food or the vegetables or anything, then that would give us energy.	Reject	Evidence-based
Ryan:	I don't agree Blair. Our energy comes from the sun but not directly from the sun. Plants give off oxygen because the air goes through a process called photosynthesis. That is the process that turns carbon dioxide into oxygen. If we didn't have the sun, plants would die, make food and air die, and we would run out of air. (Observation, 10/22/2010)	Reject	Evidence-based

After writing down their ideas, these students appeared to be explaining and elaborating their ideas more than during the discussion in Event 1. Although the debate split into two sides, those students tried to provide evidence and explanations to support their claims. After arguing back and forth, Blair came to a conclusion, "I think what we're both saying is that it has to go through a process to get to the food and to get to our bodies." Mike built his idea on Blair's, saying, "We do not directly get energy from the sun, but we need it. I think we indirectly get energy from the sun. It is a process." Most students appeared to achieve a consensus that humans indirectly get energy from the sun. In a later interview, Blair reflected on the learning process including the discussion and writing:

> When Mr. Cooper [teacher] asked the question, I thought we get energy from the sun and food. After the discussion, I changed my mind. I wrote down my idea… [writing] helped me to think about my idea again and organize my thoughts. After I wrote down my idea, I was more clear and confident and able to talk in class. We listened to each other and explained to each other. I think our discussion went very well today. We know what we need to discuss more. (Blair interview, 10/22/2010)

Blair's statement indicates that talk served as a catalyst for sharing, defending, and clarifying her understanding although the "ideas in the air" (Schoenfeld, 1989) were rambling. The writing activity helped students to organize and consolidate

(Rivard & Straw, 2000) their ideas in a coherent way. The writing provided students with an opportunity to reflect on their previous discussion as well as to achieve further results in evidence-based talk in the following discussion. When talk and writing were used in sequence, writing was initially seen as a product of the investigation, but became part of the process of investigating the relationship between the sun and energy.

Use of talk and writing simultaneously or a combination of sequence and simultaneity. It is evident that talk and writing were being used simultaneously or mixed together. For example, in Theme 3, when Nolan presented his group's claim and evidence in a whole class setting, students used talk and writing together to explain their ideas in a more evidence-based way. This example was coded in Nolan's KCT Episode 7, as shown in Figure 4.12.

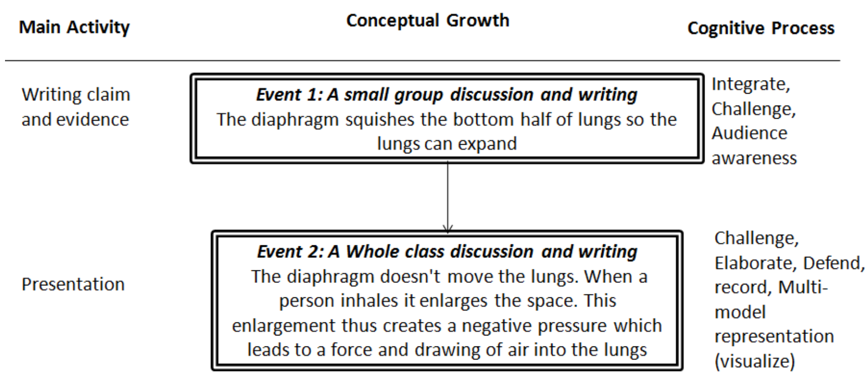


Figure 4.12 Nolan's KCT Episode 7

In Event 1, Nolan was randomly assigned to a group with Jake and Adam to investigate how the respiratory system works. They first discussed how to design and simulate the respiratory system using bottles, balloons, and straws. The following excerpts are representative of how students use talk and writing together in a small group discussion (see Table 4.13).

Table 4.13 Excerpt Illustrating Nolan's Discussion in Event 1 in Episode 7

	Small Group Discussion	**Codes**	**Sub-Codes**
Nolan:	That process is in your mouth, through the windpipe, and into your lungs. We can use the straw to represent the windpipe and the balloons to represent the lungs.	Elaborate	
Jake:	Yeah, let's do it. The bottle can be our ribcage.	Support	Simple
Adam:	Wait! Can you explain more? I do not get your idea.	Challenge	
Nolan:	See (he is drawing a picture) this is the windpipe… we had a bottle right there. Then we cut a hole in the side of the bottle…(see Figure 4.13)	Elaborate	
Adam:	How does the air go into the lung in this model?	Challenge	
Nolan:	We can blow to make the lungs swell up.	Elaborate	
Adam:	We don't always just blow it down your windpipe.	Challenge	
Jake:	Yeah.	Support	Simple
Nolan:	We can modify…. (Observation, 12/1/2010)		

During the discussion, Nolan described how the respiratory system works. However, Adam could not understand his simulation. After Nolan drew a picture, as shown in Figure 4.13, representing his model on paper, Adam appeared to realize what Nolan and Jake were visualizing and further provided a challenge to the model. This discussion inspired the students to express their idea using writing to visualize the model and challenge each other. This led them to refine the model. Nolan confessed that Adam critiqued the model and that all of his group members agreed that the model did not work. He said, "Adam thought that didn't work because there's not someone who just keeps blowing in your windpipe. We agree with him" (Nolan interview, 12/13/2010). This example indicated that students use talk and writing at the same time in small group discussions to bridge their understanding of each other's ideas.

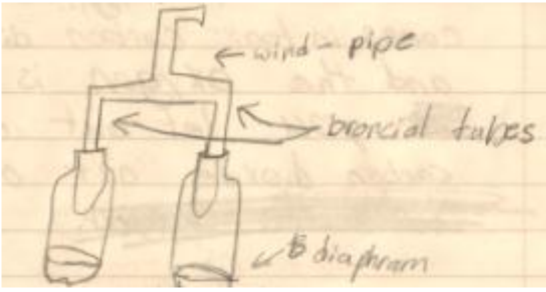


Figure 4.13 Nolan's Sketch Representing His Image of the Respiratory System

The following group activity is about writing a claim and evidence. The students wrote together discussing each sentence. For example, when Nolan wrote the sentences, *The lungs stretch out when air enters them. The diaphragm helps the lungs work*, Jake said, "The diaphragm is a muscle, we should say the diaphragm is a muscle and they work together." Adam responded "Yeah, it helps by putting pressure on the lungs so it can inhale and exhale. We have to explain it. They will ask us how the respiratory system works with other systems." They continuously examined and modified their writing during the discussion. Nolan stated his view of using these two learning tools together, "I can explain my thoughts and write them down at the same time. Then I discuss with Jake and Adam and go back to the writing. I can get more of my ideas out when I write and talk with Jake and Adam" (Nolan interview, 12/13/2010).

In Event 2, Nolan's group presented their claim and evidence to the whole class. After they presented their argument about how the respiratory system works with the muscular system, Janice challenged their evidence, "The diaphragm doesn't move the lungs; it doesn't touch them. You can't move your lungs - they're stable" (For detailed information, see Theme 3). However, Nolan and his group members tried to defend their argument, saying "The diaphragm squishes the lung!" Other students opposed this claim without any reasoning, saying "No, it doesn't" or "The diaphragm does not squeeze the lungs." The discussion appeared to be mired at a deadlock and unable to move to more advanced discussion due to the abstract concept of the respiratory system and evidence provided.

In the meantime, Nolan drew a sketch (see Figure 4.14) and explained his idea:

> The lungs need to expand when you breathe in, so the diaphragm pushes the stomach down and kind of squishes it so the lungs have room to expand like that. And then, they get full of air. (Observation, 12/13/2010)

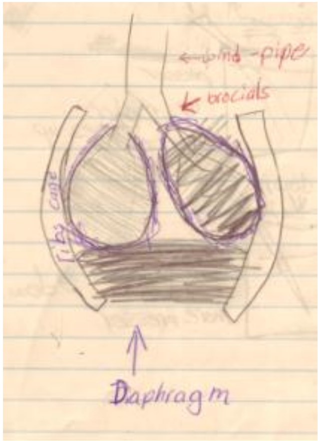


Figure 4.14 Nolan's Sketch Representing His Image of the Respiratory System

In response to Nolan's visualized model, Janice and Andrea provided another model and included more evidence to express their disagreement, as show in Figure 4.15. For the rest of the discussion, students continuously provided their evidence and explanation based upon the two models, saying things like "It [diaphragm] doesn't have to touch it and it still moves. When the diaphragm goes down, it gives it more space and it pulls the pressure down." Consequently, they co-constructed an understanding of how the respiratory system works with the diaphragm and used more evidence to support their claims.

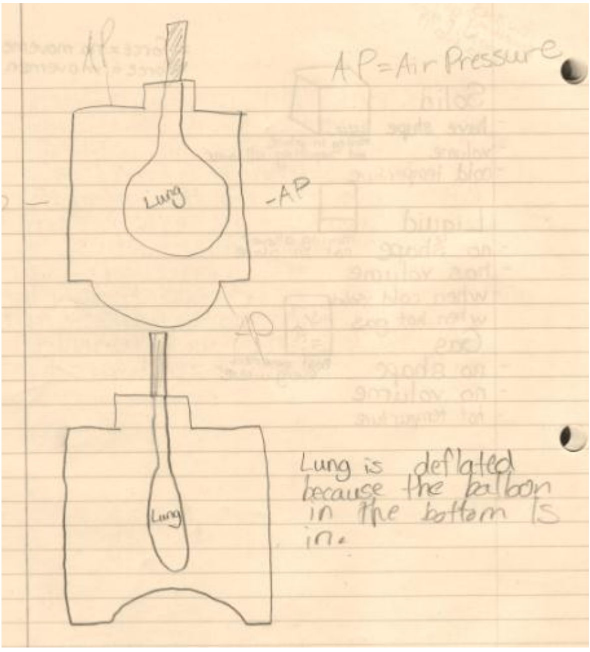


Figure 4.15 Janice and Andrea’s Sketch Representing Their Image of the Respiratory System

In the two sketches, students attempted to represent their thinking and images of how respiration works with the diaphragm to communicate with and convince their peers. Although the sketches were not scientifically correct, they represented the students’ ideas more clearly and helped their discussions move further and become more evidence-based (Field notes summary, 12/15/2010).

This episode demonstrates how students used talk and writing as learning tools together in a small group (Event 1) and in a whole class setting (Event 2). The function of writing extended from an individual learning tool supporting personal cognitive activities to a socially negotiated learning tool through combination with talk. Additionally, writing became both a product-based and process-based approach when students used it simultaneously with talk. Stated differently, writing is not simply a matter of translating preconceived ideas into text, but is a knowledge-constituting process (Galbraith & Rijlaarsdam, 1999) in which students synthesize their ideas in written forms to communicate with their peers and ultimately construct their knowledge. The quality of talk was promoted to more evidence-based when writing was used in combination with it.

Theme 7: When talk and writing were used in sequence or simultaneously, students' higher cognitive processes were provided more scaffolding than when talk or writing were used alone.

Data analysis using the constant comparative method on each episode revealed that students engaged in higher and more complex cognitive processes when talk and writing were used together than when they were used alone, as shown in Table 4.14. Table 4.14 summarizes the cognitive processes involved in the twenty-one KCT episodes in terms of the five patterns of the combination of talk and writing. For example, when students perceived and used talk and writing as separated learning tools, their cognitive processes were constrained to expressing, reporting, sharing, recording, and describing their ideas. In contrast, when students used those two learning tools together, they usually became involved in higher and more complex cognitive processes such as elaborating, organizing, reflecting, integrating, defending, using multi-model representations, and analogizing, etc. (see Table 4.14).

What follows are descriptions of how different types of students' cognitive processes were observed when different combinations of talk and writing were used.

Table 4.14 Cognitive Processes Identified in KCT Episodes according to Different Use of Talk and Writing

Cognitive Process \ # of KCT Episodes	Talk Only	Writing Only	Combination of Talk & Writing: Sequence	Combination of Talk & Writing: Combination of Sequence and Simultaneity	Combination of Talk & Writing: Simultaneity
	1	1	4	8	7
Express	✓		✓		✓
Report	✓			✓	
Share	✓		✓		
Record		✓	✓	✓	✓
Describe		✓	✓		
Elaborate			✓	✓	✓
Organize			✓	✓	✓
Challenge			✓	✓	✓
Compare			✓	✓	✓
Reflect			✓	✓	✓
Integrate			✓	✓	✓
Stimulate alternative ideas				✓	✓
Defend			✓	✓	✓
Multi-model representation				✓	✓
Audience awareness				✓	✓
Analogize					✓

Talk or writing alone. Consider an example from Blair's KCT in Episode 1 demonstrating the cognitive process of using talk only, as shown in Figure 4.16. In this episode, Blair was observed to use only talk as a learning tool in two events to construct the core concept. Her cognitive processes were mainly involved with expressing her ideas in event 1 and reporting her group's presentation in event 2.

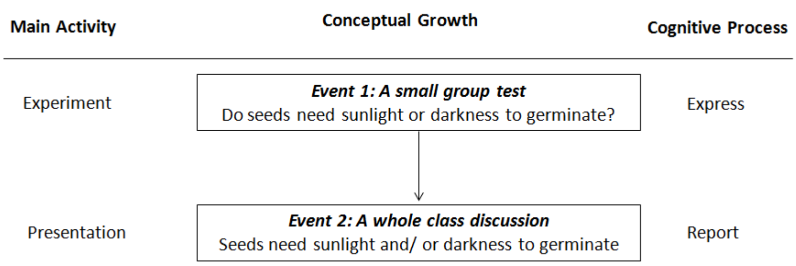


Figure 4.16 Blair's KCT from Episode 1

In event 1, Blair was randomly assigned to a small group with Olivia, Jean, and Jake to investigate what a seed needs to germinate. They chose sunlight/darkness as their control variable. “During the investigation, Blair seemed to like to express and share her ideas with her group members. When I asked her if I could see her journal, she looked embarrassed and she said ‘I did not write anything’” (Field notes summary, 9/29/2010).

In a later interview with Blair, she confessed that “I like talk more than writing. I don't really like to write, because it's just…demanding” (Blair interview, 10/1/2010).

After the investigation, Blair and her group members were asked to write down their claim and evidence on a poster in order to present to the whole class. Blair appeared to like to talk more than write. The following excerpts represent the conversation of this group (see Table 4.15).

Table 4.15 Excerpt Illustrating Blair’s Discussion in Event 1 in Episode 1

	Small Group Discussion	**Cognitive Process**
Olivia:	Three out of four grew in darkness. Four out of five grew in sunlight.	Express
Blair:	Hey, Jack, do you want to write up here “sunlight” and “darkness”?	Express
Jake:	Sure.	Express
Blair:	You're going to write H-E-L-L-A-N-D, Jean.	Express
Olivia:	Everybody wrote a part of it.	Express

The students in this excerpt were arguing about who would like to write the word on the poster and they put their data as their “evidence.” Instead of using writing as a learning tool in this event, Blair did frequently share her ideas with her group members without any reasoning, defending, or challenging observed during the conversation. They just repeated the data they obtained from observation in the poster without any reasoning to support the claim.

When her group was presenting the poster, Blair simply reported their claim and evidence and no argument followed the presentation. Similarly, Blair, in event 2, seemed never to see writing as a learning tool when she was asked to present their claim and evidence in the whole class setting. There was not much argument after their presentation. When asked about this Blair stated her perception of this presentation, “I just report our group claim and evidence, nothing else” (Blair interview, 10/1/2010).

This episode is not surprising. The role of talk is often restricted to distributing ideas and information in many science classrooms. Especially if students came from a traditional classroom where they had less experience in challenging, debating, and defending their ideas in a small group or a whole class setting, they might use talk, in general, as a tool to share ideas and report the presentation in front of the class.

Only one episode (Kurt, episode 1) was identified as using writing alone, as was discussed in Theme 6. That episode reveals that Kurt only perceived writing as a learning tool even though both talk and writing were provided in that environment. The cognitive processes were observed as recording in Event 1 and described in Event 2. He stated, “When I get a good idea I'll try to write down and stay with it. I don't care how they [his peers] judge my idea. I don't know really how they could help” (Kurt interview, 9/15/2010). In addition, he perceived writing as a tool to record data and to describe the results. He said, “If I write down at the end of the day like, what we did and stuff, then it helps like when I look back at it to see what we were doing” (Kurt interview, 9/15/2010). In this regard, using writing as the only learning tool, to a certain degree, limited Kurt’s cognitive process to recording the data and describing the results. Especially for younger students, they may not perceive how to use writing as a learning tool to construct knowledge.

Combination of talk and writing. Event 2 from Kurt’s episode 7, shown in Figure 4.17, is a representative example to demonstrate how students’ higher and complex cognitive processes were supported by using talk and writing simultaneously.

In this event, the cognitive process of elaborating, challenging, integrating different ideas in an agreement, analogizing, and multi-model representation were observed in the event.

Kurt discussed with his group members, Aaron and Mike, how the diaphragm works with the respiratory system after the term “diaphragm” was mentioned in a whole class discussion (Event 1).

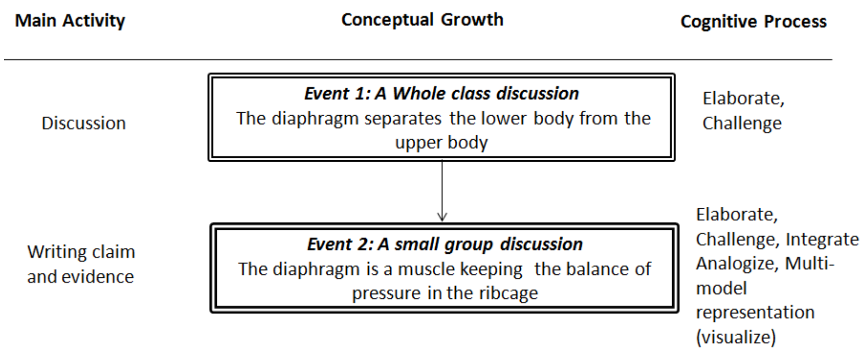


Figure 4.17 Kurt’s KCT Episode 7

Table 4.16 Excerpt Illustrating Kurt’s Discussion in Event 2 in Episode 7

	Small Group Discussion Excerpts	Cognitive Process
Mike:	How does the air get in and out? I still cannot get it.	
Kurt:	Okay. Well, this orange thing right here is the diaphragm (he draws a picture, shown in Figure 4.13). It's a muscle that separates the lower body from the upper body like the lungs and heart. Well, when we had the diaphragm on it, when you would squeeze, like when you inhale, it would get smaller. The lung would get smaller. Then when you let go, and you breathe in--I mean out, then the lung would get bigger. So, when we had the diaphragm on, when you would squeeze it, the lung would get smaller because you're exhaling.	Elaborating
Aaron:	No, I don't think so. Okay. Well, we know it's a muscle right about here (he points to the diaphragm in the picture). It separates the lungs from the lower part of the body. But the diagram does not squeeze your lungs.	Challenging
Kurt:	If the diaphragm does not squeeze the lungs, how does the air get in and out?	Defending
Aaron:	Well…like…	
Mike:	I checked the computer and it just says the diaphragm keeps the balance of pressure of our ribcage.	Elaborating
Aaron:	Yeah, without the diaphragm, the lungs aren't moving, but… With the diaphragm, the lungs go in and out. So… (They discussed the concept of the balance of pressure for about 5 minutes)	Elaborating
Kurt:	Wait! You say it keeps the balance of pressure of our ribcage. Let’s think about when you pump a syringe, there is more pressure inside and less pressure outside. When you pull the syringe, there is less pressure inside. Do you think this is like our ribcage?	Analogizing (Multi-model representation)
Aaron:	Could you draw a picture?	
Kurt:	(Drawing the pictures to represent his ideas, shown in Figure 4.14)	Visualizing (Multi-model representation)
Mike:	But how? How does the air get in and out of your body?	Challenging
Kurt:	My mom is a nurse…..	
Aaron:	I may understand Kurt’s idea. Inside your body, your diaphragm moves to get air…	Elaborating
Kurt:	You know how…your ribcage is kind of the syringe. When you breathe in…the diaphragm moves down and our lungs expand. The diaphragm causes the air pressure to change by making and keeping room for the air… (He is drawing a picture, shown in Figure 4.15)	Visualizing (Multi-model representation)

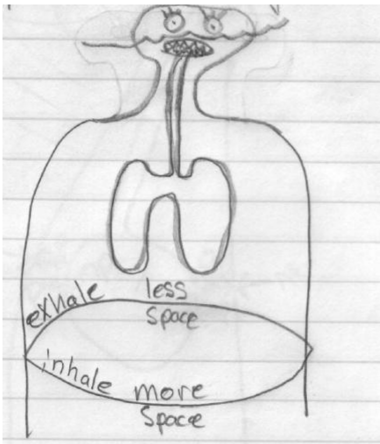


Figure 4.18 Kurt's Sketch to Represent His Idea about How the Diaphragm Works with the Respiratory System

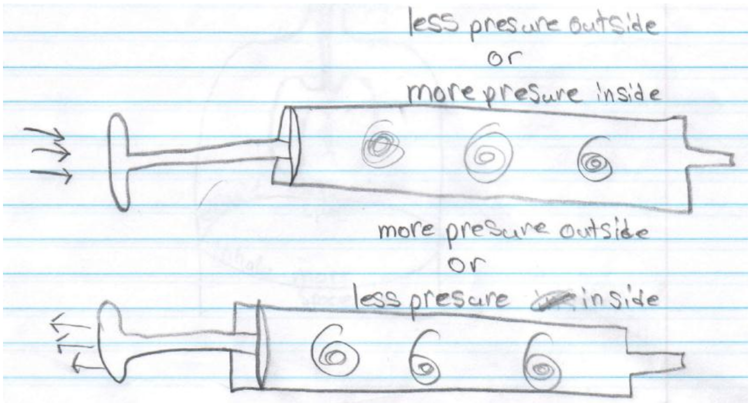


Figure 4.19 Kurt's Sketch of His Analogy to the Syringe Model

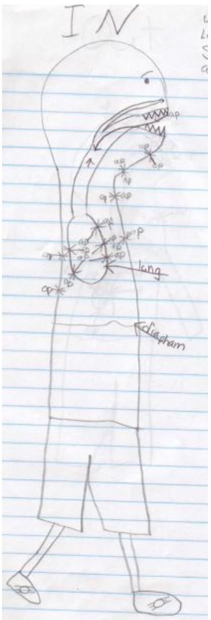


Figure 4.20 Kurt's Sketch to Represent the Balance of Air in the Ribcage

The discussion was very animated, with students arguing back and forth about their various interpretations of the function of the diaphragm in the respiratory system by fluently using talk and writing together. First, a cognitive process with challenging responses continuously occurred in this event when students talked about their ideas in association with written forms. After Kurt drew his model about how the diaphragm works with the lungs, shown in Figure 4.13, Aaron and Mike better understood Kurt's ideas and started to critique Kurt's model. Kurt's sketch, associated with his reasoning, advanced their conversation to a more argumentative level, which involved challenging, defending and elaborating responses. Kurt pointed out that his sketch deepened their discussion although his idea was not correct at that moment. He said, "They more understood my idea after I drew the model…Aaron challenged my model and I started to think if I am wrong" (Kurt interview, 12/13/2010).

Second, the use of analogy, as a core cognitive process (Clement, 1998), emerged in this event when Kurt tried to understand the balance of pressure in a ribcage, shown in Figure 4.14. After Mike mentioned the idea about the balance of pressure, Kurt drew a picture about a syringe to explain the balance of air pressure outside and inside the syringe. He further analogized the syringe model to the human respiratory system to explain how the diaphragm keeps the balance of air pressure in a ribcage. This example indicated that Kurt used those two representations to present a familiar analogy to support his interpretation of the respiratory system, which he apparently found more abstract and less familiar. After Kurt drew those pictures and discussed his reasoning, Mike seemed to understand Kurt's ideas and how the diaphragm works with the lungs.

Third, Kurt continuously used different models to represent his image of the respiratory system. Using different representations other than texts, like diagrams and pictures, made the difficult and abstract concepts more intelligible to other group members and moved them toward more sophisticated cognitive and conceptual learning. Kurt states, "Drawing a picture can make others understand my ideas clearer and we can go from there" (Kurt interview, 12/13/2010). However, using different models to represent his ideas did not occur naturally. Rather, higher cognitive processing occurred in this event because his classmates continuously challenged Kurt and asked him to clarify his ideas. These verbal challenges fostered more sophisticated cognitive approaches that led students to use multi-model representation to represent their ideas. As an example, this event showed how talk and writing supports students' involvement in higher and more complex cognitive processes such as challenging, analogizing, and using multi-model representations.

In conclusion, talk and writing used separately may not lead students to higher cognitive processes. However, when students are able to perceive both talking and writing as interdependent learning tools, there appears to be a more sophisticated approach toward cognition.

Theme 8: While the use of talk and writing separately was more teacher-directed, the use of talk and writing simultaneously produced more student-directed learning.

To examine changes in the use of talk and writing over time, 52 events that constituted the twenty-one KCT episodes were grouped into three categories according to what learning tool was utilized in each event: (1) only talk, (2) only writing, and (3) both talk and writing (See Table 4.17).

Table 4.17 Number of Events Identified in Each Unit for Each Student

Topics	Students	Learning Tool(s)		
		Talk Only	**Writing Only**	**Talk & Writing**
Unit 1 : Ecosystem	Kurt	4	5	2
	Blair	6	1	2
	Nolan	3	3	2
Total		13	9	6
Unit 2 : Human Body System	Kurt	0	1	7
	Blair	0	1	8
	Nolan	0	1	6
Total		0	3	21

As shown in Table 4.17, students came to use the combination of talk and writing to construct their knowledge more as they had more opportunities to engage in argument-based inquiry. For example, the frequency of using talk or writing alone was decreased from 13 and 9 in the first unit to zero and 3 in the second unit, respectively. In contrast, the frequency of the combination of talk and writing was increased from 6 in the first unit to 21 in the second unit. This result, to a certain degree, corresponds to Cavagnetto, Hand, and Norton-Meier's (2010) findings that students increased their talk over time when it was associated with writing in argument-based inquiry. This trend of using talk and writing together in constructing scientific knowledge over time might result from two possible reasons: (1) students came to take ownership for their learning, and (2) students came to understand the meaning of negotiation.

Taking ownership for learning. This chapter presented some examples that showed different patterns of using talk and writing to construct knowledge in the argument-based classroom in Theme 6 and Theme 7. The examples also show that, to a certain extent, as students used talk and writing together, they came to take ownership for their learning. That is, students came to direct what and how they were going to learn in that context. For example, in Theme 6, Nolan's KCT Episode 7 indicates that he actively elaborated and defended his ideas by using talk and writing in two events without teacher intervention. Not only did Nolan direct the process of knowledge construction in the episode, but this example also illustrates that Nolan fluently used talk and writing as learning and representation tools to debate his peer's challenging question.

Similarly, in Theme 7, Kurt's Episode 7 also indicated that he directed the orientation of learning by himself through using talk and writing as learning tools in that event. When Kurt engaged in the group discussion, he attempted to clarify his idea by using writing to visualize. Talk and writing became learning tools to facilitate Kurt's knowledge construction, rather than simply learning how to use talk and writing. During the entire process, the teacher did not come to the group and gave no direction or feedback. Students totally controlled their learning under these conditions. This would suggest that there are important ramifications arising from the teacher's decision not to come to direct the group. A pedagogical shift has occurred that creates a classroom environment that enhances students' ownership of learning, and this results in more active participation by the students.

In a later interview, Kurt expressed his view about learning science in the latter part of the semester:

> I didn't think it was that much fun [in the beginning of the semester] because all we really did is talk about stuff and write stuff on the board. But now we do all kinds of the experiments and negotiating and stuff, so now it's pretty interesting. We decide our research questions, design experiments, and negotiate our ideas and stuff, so now it's pretty interesting. (Kurt interview, 12/14/2010)

As exemplified by this statement, Kurt came to understand that he claimed ownership for his learning and could play the director role for the process of his knowledge construction. Nolan, likewise, described the difference in his view toward learning science at the beginning and the end of the semester. He said:

> [In the beginning of the semester] we did sort of just follow a sheet of paper. We thought we cannot change anything. Just that I had a cup of soil in it and put it under a light….But now we have our own question, and we have to test by ourselves. The interesting part is to write up our claim and evidence and negotiate it in class. We decide whether our evidence supports the claim. (Nolan interview, 11/30/2010)

Similarly, Nolan came to realize that his role in learning changed across the semester. Additionally, he also began to use writing and talk as learning tools to construct his knowledge in negotiated activities.

In contrast, when students used talk or writing alone in an event, they perceived that the teacher directed their learning processes. For example, in Theme 6, Blair's KCT Episode 3 consisted of four events and each event only used one learning tool. Importantly, each event was directed by the teacher. In Event 1, the teacher initiated the question (Do humans get their energy from the sun?) for students to debate. In Event 2, the teacher also led the direction of the discussion. At the end of Event 2, the teacher played the director role to end the students' discussion and make them write down their ideas, which consisted of Event 3. In Event 4, the teacher also played the director role in the beginning of the discussion. This example illustrates that when the event is more teacher-directed, students appeared to only use a learning tool in that event to construct knowledge.

Additional support for this claim can be seen in the following excerpt from an interview with the teacher about the role of talk and writing in the classroom. He said:

> In the beginning of the first unit, it was more just a job or a task I assigned. They had to do it. Now they're more willing to do it. And they're starting to see both perspectives of, "It helps me think through my ideas, but it's also for the purpose of sharing my ideas…both the construction of looking for critiques. So as I'm sharing it out, I need to make sure I'm writing for the purpose of getting critiqued instead of just putting ideas down." (Teacher interview, 11/23/2010)

At the beginning of the class, “students always paid attention to the teacher. They worried about whether their answer was right or not and whether they went in the right direction. They usually followed the teacher’s ideas to conduct the activities” (Field notes, 10/15/2010). However, as students engaged in more argument-based inquiry, “They seemed to realize that they took responsibility for their learning. They gradually debated, clarified, and challenged each other’s ideas. Talk and writing were frequently used together in the discussion as constructing knowledge and critiquing tools” (Field notes, 12/14/2010).

The meaning of negotiation. The students’ shift in use of talk and writing together was closely related to their increased understanding of the meaning of negotiation in an argument-based classroom. For instance, Blair expressed her view about negotiation in the beginning of the semester, “We just presented it [poster] and handed it in” (Blair interview, 9/30/2010). However, in the middle of the semester, Blair appeared to change her perspective about negotiation, “We actually have to explain why we do this and how it did this. We give the feedback instead of the teacher…We have to write down our ideas and negotiate it and revise” (Blair interview, 11/15/2010). At the end of the semester, Blair provided a more sophisticated perspective of negotiation, “We tried to explain to each other why we disagreed and agreed. We finally have to go to the same idea...To explain our idea, we sometimes draw a picture or a diagram to show our thought in negotiation” (Blair interview, 1/05/2011).

These statements show Blair’s shift in view of negotiation, which was also closely related to her use of talk and writing in argument-based inquiry. Instead of using talk and writing separately, she came to use the two tools together as negotiation tools by the end of the semester. This result also responded to Theme 1 and Theme 3. As students had more opportunities to engage in argumentation, their understanding of negotiation became more sophisticated, which led them to use more argumentation components in the processes. Importantly, then, talk and writing became negotiation tools for the argumentative practices.

Taken together, not only did students integrate talk and writing in their negotiations to construct knowledge, but they directed their learning more by using these two learning tools to represent, construct, and critique ideas. Instead of only learning how to use these two learning tools, they came to embed these two learning tools in their argumentative practice over time.

Summary

Grounded in interactive constructivism and using language as a learning tool, this study identified six core components of argumentation, characterized students' argumentative practices, demonstrated five patterns of using talk and writing as learning tools to construct scientific knowledge, and discussed cognitive processes according to five patterns in terms of the use of talk and writing in an argument-based classroom over sixteen weeks. Three major findings were discussed in this chapter: (1) increased understanding of argumentative components in public negotiations, (2) increased ability of crafting written argument, and (3) identifying five patterns of the use of talk and writing for knowledge construction and cognitive processes according to each pattern.

First, students developed and used more argumentation components over time. As the number of argumentation components increased, students began to use evidence to challenge, defend, reject, and support arguments. The focus of negotiation was shifted over time from asking about the correctness of a claim to stressing the relationship of question, claim, and evidence. Students also came to understand the value of peer feedback which, to some degree, led them to be more willing to rethink their original ideas and engage in effective negotiated processes.

Second, students' ability to craft a written argument improved over time in five aspects: (1) the accuracy of a claim, (2) the sufficiency of evidence, (3) the quality of reasoning, (4) the relationship between a claim and question, and (5) the relationship between a claim and evidence. The result, with a parallel shift between oral argumentative practices and the quality of written arguments, indicates talk and writing, to a certain extent, are interdependent.

Building on these findings, this study further identified five patterns of using talk and writing in an argument-based classroom: (1) talk alone, (2) writing alone, (3) the use of talk and writing in sequence, (4) the use of talk and writing simultaneously, and (5) the combination of sequence and simultaneity. Students tended to use the combination of talk and writing, especially the use of talk and writing simultaneously, to construct their scientific knowledge after they had more opportunities to engage in an argument-based inquiry classroom. Students' cognitive processes in higher order and more complex levels were promoted when they used these two learning tools together. Importantly, while using talk and writing separately appeared to be more teacher-directed, using these two learning tools together appeared to produce more student-directed learning. This, in large part, might have resulted from students' awareness of the ownership for their learning and the meaning of negotiation.

The next chapter will discuss how these findings contribute to understandings about fostering productive argumentation in science classrooms and will provide insights into theoretical claims regarding the value of using argumentative practices at the elementary school level.

CHAPTER FIVE
CONCLUSION AND IMPLICATIONS

The goal of this study was to examine students' understanding of argumentation when talk and writing were provided as learning tools as well as to explore how talk and writing can best support students' construction of scientific knowledge. Results from this study highlight the difficulties and challenges that students faced in shifting their learning practice from a traditional style to a more argument-based approach. The students struggled with the change not because they were unwilling, but because they were unfamiliar with the process of argumentation and how to use language as a learning tool. As students encountered more opportunities to obtain "a grasp of the practice" (Ford, 2008) they were observed to develop a more sophisticated understanding of argumentation, use talk and writing as learning tools to construct and negotiate their ideas with peers, engage in more complex and higher-order cognitive processes, and take ownership of their learning in science.

This chapter begins with a discussion of the main findings addressing the research questions from six aspects: (1) understanding of argumentation, (2) ability of crafting written argument, (3) use of talk and/ or writing, (4) cognitive processes, (5) meaning of negotiation, and (6) methodology consideration. The first five aspects are summarized in Table 5.1 based upon the stage of students' engagement with argument-based inquiry. The sixth aspect, then, is discussed in light of the overall study design and the contribution of the in-depth analysis of knowledge construction trajectory episodes for science education. Additionally, theoretical and pedagogical contributions of this study are discussed. Finally, the limitations of the study and possible directions for future research are provided.

Table 5.1 Matrix of Argumentative Practices in Understanding of Argumentation, Written Arguments, Use of Talk and/ or Writing, Cognitive Processes, and Negotiation

Time Line	Understanding of Argumentation	Written Arguments	Use of Talk and/or Writing	Cognitive Processes	Meaning of Negotiation
Week 1-3	--Information seeking (great proportion) --Elaborating --Challenging (focus on the procedure, process, and the accuracy of a claim) --Rejecting, supporting, and defending (simple)	--Focus on the accuracy of a claim --Audience is the teacher --The reason to change ideas is because of teacher's hint	--Talk or writing alone (writing is a product) --Use talk and writing in sequence (writing is a product, then becomes a process)	--Expressing, reporting, recording, describing, and elaborating	--Teacher-directed --Negotiation is to talk out ideas --Students usually talked over each other
Week 4-12	--Information seeking (small proportion) --Elaborating --Challenging (focus on the structure of an argument: question, claims, and evidence) --Rejecting, supporting, and defending (more evidence-based)	--Focus on the relationship between question, claims and evidence --Awareness of audience shifting from teacher to peers	--Combination of sequence and simultaneity	--Elaborating, organizing, challenging, comparing, reflecting, stimulating alternative ideas, defending, multi-model representing, and audience awareness	--Transition from teacher-directed to student-directed --Negotiation is to explain ideas and to revise them --Students began to realize the value of critique and listening
Week 13-16	--Information seeking (small proportion) --Elaborating --Challenging (focus on the quality of evidence: sufficiency, validity, and reasoning) --Rejecting, supporting, and defending (evidence-based)	--Focus on the sufficiency and reasoning of evidence --Audience is both teacher and peers --Willing to change or shift ideas based on peers' feedback if useful	--Use talk and writing simultaneously in a whole class setting or a small group (writing is product and process in that context)	--Elaborating, organizing, challenging, comparing, reflecting, stimulating alternative ideas, defending, multi-model representing, audience awareness, and analogizing	--Student-directed --Negotiation is to explain ideas and reach a consensus; provide evidence to support claim --Effective dialogue: students realized the importance of critiquing, constructing, and listening

Discussion of Findings

Understanding of Argumentation

While many of the studies to date have focused on how students use the structure of argument in secondary schools, this current study examined the nature of argumentation within the context of the elementary school. This study identified six core components of argumentation developed by fifth-grade students in an argument-based classroom: information seeking, elaborating, challenging, rejecting, defending, and supporting in public negotiations. This study suggests that, when students were given opportunities to ask questions, generate claims, and interpret data as evidence, they gradually linked the use of those argumentation components with the negotiated processes. This suggests that elementary students' argumentative practice can go beyond "doing the lesson," as proposed by Jimenez-Aleixandre et al. (2000). In this study, this capacity seems to depend less upon age and more upon experience and practice.

Engaging students in productive scientific argumentation is challenging and can be a long-term process. The results suggest that the ability to understand argumentation does not come naturally to most individuals (Schwarz, 2009) but rather is grown through practice (Martin & Hand, 2009). As shown in Table 5.1, students at the beginning stage focused more on information seeking and elaborating components, rather than on developing challenging, rejecting, defending, and supporting components which are critical for argumentation (Sampson, Grooms, & Walker, 2011). Consequently, students at this stage appeared to be less engaged in critiquing or persuasive strategies than in information seeking—they seemed to be working to make sense of peers' arguments but rarely to be determining whether they were persuaded by them. However, when students were given more time to speak and their argumentative practice was encouraged, they frequently used challenging, defending, rejecting, and supporting components. Students thus gradually shifted their argumentative practice to *critique* as well as *constructed* scientific knowledge in public negotiations. Like the example provided in Theme 1, when Kurt presented an argument in the whole class setting, his peers (Grey and Megan) helped him respond to the challenging questions and elaborate his claim and evidence. As a result, they constructed more complete scientific knowledge by using argumentation components during negotiations.

One distinguished argumentative model, based on the way that the scientific community works, has been conceptualized by Ford (2008) as a dialectic between *construction* and *critique* of claims in both scientific reasoning and practice. According to Ford (2008), scientific argumentation necessitates that individuals move between constructor and critique roles as they work to persuade others and construct new knowledge. However, translating this model to science classrooms remains undefined. The findings of the current study suggest that these six core components can enable students to move between constructor and critique roles when engaging in argumentative practices. Like the example shown in Theme 3, when Nolan presented his model to the class, Janice and Andrea challenged his model of the respiratory system. In responding to the challenges, Nolan elaborated on and defended his ideas by providing evidence and explanations. Consequently, Nolan was persuaded by his peers' evidence-based talk and accepted the argument proposed by Andrea. Those students moved between constructor and critique roles during the conversation by using the six core components in the negotiation. These six core components helped the students understand how to play the role of constructor and critique appropriately, which basically involves how to scrutinize the explicit connection demonstrated between a question, claim, and evidence.

In addition, this study found that students were more willing to shift or revise their ideas if peers' discussion and feedback was evidence-based. Students, at the beginning or middle of the semester, were talking over each other without providing solid evidence to support claims when they defended, rejected, or supported others' ideas. Students' discussion without evidence and reasoning support was limited and ineffective, resulting in their unwillingness to shift or revise ideas. It appears that these students struggled with using the argumentative context as an opportunity to refine their own thinking (Berland & Reised, 2011). Berland and Reised (2011) have indicated that students rarely revised their ideas in light of the challenges and questions posed. Similarly, Kuhn and her colleagues (D. Kuhn, 1989; D. Kuhn, Amsel, & O'Loughlin, 1988; D. Kuhn, Black, Keselman, & Kaplan, 2000) also reported that students struggled to reinterpret evidence after class discussion.

However, this study did find that students at the end of the semester were more willing to revise their ideas if their peers provided evidence to support their opinions. These findings, therefore, suggest that a challenge component is necessary for argumentative practice, but it is not enough. Evidence-based defending, supporting, and rejecting components may help students to rethink, reflect, and compare their ideas to those of others with evidentiary support. These components and actions may ultimately result in students revising their ideas and reconstructing their scientific knowledge through argumentative practice.

The significance is, then, that only using talk as a learning tool may not produce evidence-based defending, supporting, and rejecting discussions. As several examples shown in Themes 3, 5, 6, and 7 demonstrate, when students engaged in evidence-based discussion, they usually used writing associated with talk as negotiation tools to help them explain and elaborate their ideas. Ultimately, students constructed their "new" knowledge by combining these two tools of negotiation. Galbraith (1999) argued that the writing process[6], when accompanying representational talk, is a knowledge-forming process. While the quantity and quality of talk are important, this current study suggests that writing also plays a significant role in knowledge clarification and construction.

[6] The writing process is not limited to producing texts. Rather, the process includes multi-model representations.

Written Arguments

One of the major findings of this study indicates that there is a relationship between the way these students participated in argumentation and their abilities in crafting written arguments. Examining Theme 2 and Theme 5 together, at the beginning of the semester students focused on challenging the test procedure and accuracy of claims, which was reflected in the improved quality of their written arguments about the accuracy of claims. In the middle of the semester, students' spoken challenges focused on the structure of the argument, which was also reflected in their improved quality of writing about the relationship between question and claim and the relationship between claim and evidence. At the end of the semester, students moved to challenge the quality of evidence, which was reflected in their improved quality of written arguments regarding reasoning and sufficiency of evidence. These observations, when taken together, indicate that there seems to be a positive relationship between students' participation in argumentation and writing as outcome measures.

This result responds to Reznitskaya, Anderson, and Kuo's (2007) study. They found that student performance on a reflective essay was improved only by their participation in discussions, in comparison to students who did not participate in discussions. Along the same lines, Sampson, Grooms, and Walker (2011) found that groups that had higher levels of disciplinary engagement in scientific argumentation also crafted higher quality written arguments. Building on these studies, the research conducted in this study suggests that talk and writing are interdependent. However, it is believed that improved performance in one practice does not necessarily lead to better performance in the other; instead the students seemed to develop better awareness of audience and understanding of claim/ evidence, which guided how they engaged in both practices.

One key finding was that students developed an awareness of audience for oral argumentation and written arguments over time. Some researchers may argue that it is not necessary for students to develop awareness of audience when engaging in oral argumentation due to the nature of the activity. However, in Theme 8, the findings showed that in the beginning of the semester the students' audience for oral discussion was the teacher, rather than their peers. Although these students were required to present their written arguments to the whole class, they always paid attention on the teacher's reactions and feedback. Similarly, at the beginning of the semester the students' audience for crafting written arguments was the teacher. Indeed, this situation frequently occurs in traditional science classrooms. When students are assigned a task to write an argument and present it to the whole class, they usually pay attention to the teacher's reactions. Nevertheless, when these students engaged in the negotiations embedded within argumentative practices, this study found that students came to understand that their audience is not only the teacher, but also their peers. Feedback can come from the students themselves as well as the teacher. The findings indicate that students' shift in the awareness of audience resulted from their increased understanding of argumentation. This understanding then became part of their reasoning processes and they were able to write and debate questions involving arguments.

A seconding finding was that students developed a better understanding of the criteria and norms of what counts as evidence and what counts as a claim. Additionally, they also learned the criteria and framework of how to evaluate an argument. As examples shown in Themes 2 and 5 indicate, at the beginning of the semester, the students focused on surface declarative knowledge to evaluate ideas and did not include genuine evidence to support claims in their written arguments. However, after obtaining "a grasp of practice" (Ford, 2008), students came to understand the difference between data, claims, evidence, and reasoning as well as to develop new criteria to evaluate and critique each other's ideas. This epistemic shift from the focus of *what we know* to the emphasis on *how we know what we know* and *why we believe what we know* (Duschl, 2008) requires a different classroom culture and discourse environment (Cavagnetto, 2010). It is speculated that this epistemic shift requires two conditions to occur: (1) students must be introduced to new criteria or norms for what counts as a claim and what counts as evidence in an explicit fashion in an appropriate context and time, and (2) students need to be encouraged by others to use these new criteria and norms in an appropriate context and time in which they are fruitful and make sense. In other words, students gain valuable and useable understanding through engaging in argumentative practice, rather than learning these criteria and norms before doing science. Argumentative practice should be embedded in different inquiry areas that provide meaningful context for students to engage in the activities of arguing to learn and learning to argue. However, these speculations go beyond the focus of this study and will require more targeted research to substantiate.

A third important outcome of this study was that the students were able to transfer their understanding of argumentation from the first unit to the second unit. As observed, not only initially talkative students but also quiet students seemed to transfer their skill of argumentation from one context to another. However, the researcher agrees with Cavagnetto's (2010) perspective and argument. The students transferred their understanding of scientific argumentation and practice, not only their skills of argumentation. The skills of argumentation include knowing and applying the argument structure and understanding science principles and processes. Argumentative practice includes not only knowledge of argument structure, but also of the abstract nuanced features at the junction of science processes, argument structure, and construction of scientific conceptual knowledge. For example, through argumentative practice this study found that students developed a sophisticated understanding of the nature of argumentation, realized the argument structure, and advanced their understanding of negotiation. Therefore, the goal of argument instruction in a science context is not only the transfer of argumentation skills but rather the transfer of an understanding of scientific practice.

A fourth finding was that students' written scores on the aspect of reasoning evidence were lower than on other aspects through the two units. However, when comparing students' reasoning scores in the first and second unit, students apparently improved their reasoning abilities on writing arguments in the second unit. This study also found that students came to use different models to represent their ideas and images in the oral discussion, which also applied to their written arguments (Theme 3 and Theme 6). The result does raise a question about the value of encouraging students to explain a concept or knowledge claims by using multi-model representations in crafting written argument and oral discussion. Previous studies have revealed that students have difficulty providing backing for their claims and evidence both in their written arguments (Bell & Linn, 2000; McNeill et al., 2006) and during classroom discussion (Jiménez-Aleixandre et al., 2000). The researcher conjectures that students' difficulty with reasoning made the value of multi-model representation particularly important for this component of argument throughout the two units. Ainsworth (1999) highlighted how the use of multi-model representations led to a deeper understanding of concepts that may include promoting abstraction and encouraging generalizations between representations (Hand, Gunel, & Ulu, 2009; Wu, Krajcik, & Soloway, 2001). Asking or encouraging students to use multi-model representations may foster their ability to clarify and revisit their ideas instead of relying only on talk or one model (text) for reasoning concepts.

The Use of Talk and Writing

This study demonstrated that students used talk and writing simultaneously to construct their scientific knowledge at the end of the semester in both whole class discussions and small groups (Themes 3, 6, and 7). The use of talk and writing was embedded in the students' investigations and negotiations and became an integral part of inquiry as students became capable of using the two tools to represent their arguments, analyze data, and debate their ideas. During interviews, students confessed that talk associated with writing helped them to clarify and visualize their ideas, which drew them to discuss concepts at a deeper level. These findings suggest that in argument-based inquiry learning environments, talk and writing were recognized and internalized by students as learning and negotiation tools to construct knowledge. Using these two learning tools to negotiate became part of classroom culture (Hand, 2008; Kelly & Chen, 1999) that matched with those in the community of scientists as proposed by Norris and Phillips (2003).

Some interesting questions and dilemmas are raised from the findings about the combination of talk and writing to construct knowledge in argument-based inquiry. What is the value of the simultaneous use of these two tools? What are the differences among use of talk alone, use of writing alone, and simultaneous talk and writing? As the examples shown in Themes 3, 6 and 7 indicate, students' writing (drawing) to visualize their thinking and image of the respiratory system in a written form brought their discussion to a deeper level and clarified their ideas in that context. This kind of talk associated with writing, as Galbraith noted (1999), required an oscillation between disposition (targeted topic) and linguistic (writing task) knowledge, which led to clarification of conceptual understanding and may lead to the formation of new knowledge. In Themes 3 and 6, Nolan did shift and reconstruct his idea after discussion with his peers by using writing at the same time. This kind of talk associated with writing also helped him to clarify his idea to other students and ultimately led them to construct more complete scientific knowledge.

Importantly, talk associated with writing is different from either student-generated argument by talk or individual writing of the argument. Talk associated with writing occurred within the group context or whole class setting and therefore the discourse was under scrutiny from the collective body rather than separate individuals. Alternative ideas were therefore stimulated by other students' critiques. As such this kind of talk associated with writing, similar to talk, is a collaborative effort.

In addition, talk alone simply deposits ideas that are not recorded. It is difficult to go back to check an idea generated 10 minutes ago. By contrast, the form of talk associated with writing for sharing, challenging and defending is an interaction between students and texts which is represented by someone. Talk associated with writing encourages students to "freeze" their ideas on paper, which records them. Students can frequently collaboratively reflect on their ideas based upon their writing. The role of writing in this case "serves learning uniquely because writing as process-and-product possesses a cluster of attributes that correspond uniquely to certain powerful learning strategies" (Emig, 1977, p. 122).

Another pattern of the combination of talk and writing is the use of the two learning tools in sequence. As shown in Theme 6, Blair perceived that writing following talk helped her to reflect and reorganize her ideas in a logical and coherent way after a rambling and divergent discussion. In addition, talk following writing encouraged their discussion to be more evidence-based. This finding provides empirical evidence verifying several scholars' "hypothesis" about the value of the use of talk and writing in sequence (Berland & McNeill, 2010; Jiménez-Aleixandre & Erduran, 2008).

Previous studies on argumentation have focused on the value of talk (e.g. Scott et al., 2006) or the value of writing (e.g. Bangert-Drowns et al., 2004), but in the context of the current study the researcher would argue that the combination of talk and writing has value. This does not mean that the role of writing or the role of talk in science classrooms should be underestimated. As Chapter Two's review of literature shows, there are a number of positive effects of promoting students' learning science by using talk or writing (e.g., Lemke, 1990; Klein, 1999). However, the analysis of this study led the researcher to rethink the value of the combination of talk and writing to promote students' construction of science, as it appears to help students engage in more productive arguments than when using talk or writing alone.

To summarize, the results reported here suggest that the combination of talk and writing is critical to facilitating argumentative practices for learning science. Thus, in designing successful and productive argument-based inquiry environments, this kind of language use in science should be emphasized as a form of inquiry. Researchers and educators should "design sequence of instruction that provides opportunities" for student growth (Duschl & Ellenbogen, 2002, p.3).

Cognitive Processes

Another important finding of this study was that students engaged in higher-order and more complex cognitive processes when talk and writing were used together either in sequence or simultaneously, rather than when they were used alone. In other words, talk and writing used separately may not lead students to higher-order cognitive processes. However, when students were able to perceive both talk and writing as interdependent learning tools, they appeared to employ a more sophisticated approach toward cognition. This is yet more evidence supporting the value of using talk and writing together in argument-based inquiry.

In terms of the relationship between the use of these two learning tools and cognitive processes, the researcher raises the following questions from the results of this study: Does the use of talk and writing simultaneously or in sequence lead to students' complex and higher order cognitive processes? Or do students who have higher cognitive reasoning skills cause the use of talk and writing? In other words, a student with higher cognitive reasoning skills in a typical science classroom task might use more strategies while a student who is less adept at scientific reasoning might use fewer. To answer these questions, let's consider the examples in Themes 6, 7, and 8 demonstrated by Kurt.

The example in Theme 6 shows that Kurt, at the beginning of the semester, heavily relied on the use of writing to record data and to report group arguments to the whole class. However, in the example in Theme 7, at the end of the semester Kurt frequently used these two tools in the same event to construct the core concept. He used writing associated with talk to elaborate and defend his ideas, further analogized the syringe model to the human respiratory system, as well as adopted different models to represent his ideas about the respiratory system. This progression of the use of talk and writing as learning tools to negotiate in group discussion seems to have resulted from his understanding of the value and the role of language in argument-based inquiry. In the interview, he recognized that using these two learning tools to negotiate with his peers helped him to clarify his ideas and led to peers challenging his ideas. After challenging, he began to rethink and reflect on whether his model was able to explain the respiratory system. His improved understanding of the role of language further led him to engage in more complex and higher order cognitive processes. However, this progression was not automatic and did not occur in a short period of time. The research suggests this kind of shift requires that the teacher build an environment for students and teach them how to use the language in that context just at the right moment. This is beyond the focus and analysis of this study. During the researcher's observation, the teacher usually taught students how to use writing to represent their ideas in a whole class discussion or a small group investigation, rather than teaching them before doing science. Nevertheless, this conjecture will require more targeted research to substantiate.

The Meaning of Negotiation

In addition to the understanding of the value of language for negotiation, the use of talk and writing together in argument-based inquiry also resulted in students taking ownership of their learning as well as in an increased understanding of the meaning of negotiation (Themes 1 and 8). The findings have shown that students took ownership for their learning when they used the combination of talk and writing to negotiate by the end of the semester. Using talk and writing became part of classroom culture that matched that in the community of scientists as proposed by Norris and Phillips (2003). The researcher suggests that students need to learn to take ownership or responsibility for their learning. Ownership in this pedagogical scheme lies in the classroom community, but this does not imply that “anything goes” or that the teacher has no voice (Ford, 2008). The teacher has a responsibility to challenge students’ claims and evidence when students are not able to mediate effectively. Additionally, teachers must provide appropriate scaffolds that aid students’ understanding of the value and the use of language and the meaning of negotiation.

More importantly, the teacher should create a discourse space (Marton & Tsui, 2004) in which students can construct an argument as part of an investigation with their peers, clarify their thinking by using the six core argumentation components, monitor their conceptual understandings, as well as learn and use the criteria by which these arguments will be judged or evaluated. Talk and writing can be powerful means by which to foster students to engage in higher cognitive reasoning. Especially, the simultaneous use of talk and writing can be an effective way to help students develop ownership of their learning, participate in more productive argumentative practices, and advance their conceptual growth.

Methodological Considerations

This study applied three analytical approaches to the same data set to triangulate the findings and thereby strengthen interpretations. The first two analytical approaches (the constant comparative method and the enumerative approach) are commonly used by many qualitative researchers in science education. The third analytical approach (in-depth analysis of knowledge construction trajectory (KCT) episodes) was purposefully designed for the current study to answer the second research question. This approach is built on the assumption that students are able to construct knowledge through argumentative practice (this issue still remains undefined). The results, to a certain degree, provide evidence to show that students are able to build scientific knowledge through practice.

In addition, although many scholars emphasize the value, use, and patterns of the combination of talk and writing in argumentative practice, few studies provide empirical evidence to support that practice. Most researchers have applied the constant comparative method, the enumerative approach, or quantitative approaches for analyzing the data in their studies (Berland & Reiser, 2011; McNeill & Pimentel, 2010; Peker & Wallace, 2009; Rivard & Straw, 2000). However, argumentative practice and the use of different forms of language are complex and complicated. Only relying on the constant comparative method or the enumerative approach may not effectively portray the nature of the use of language for knowledge construction in argumentative practice and may limit the result to only one learning tool (talk or writing).

Accordingly, in this study, an in-depth analysis of knowledge construction trajectory (KCT) episodes was developed with the aim to portray the complex process and patterns as well as to make the process more visible through quantification and visualization of argumentative practice. This approach can afford researchers the opportunity to explore the ways in which students use different learning tools through argumentative practice to construct scientific knowledge. Also, this approach opens a door to purposefully using creative qualitative approaches to explore complex issues and contexts.

Conclusion

In closing, the findings of this study may provide new insights for science educators and instructional designers interested in promoting and supporting argumentation inside science classrooms. Six components—information seeking, elaborating, challenging, defending, rejecting, and supporting—were identified as being critical for knowledge construction in argumentative practice in which talk and writing activities were sequenced, integrated, and embedded in scientific inquiry. Using these six components can positively impact students' knowledge construction and ultimately improve their understanding of argumentation. Additionally, these six components can provide teachers with an outline of argumentative practice and guidance for designing argumentative environments.

The results also demonstrated what is possible in science classrooms when talk and writing are used in more interactive and educative ways. Much work remains to be done to evaluate the efficacy of the combination of talk and writing and the six core components in a wide range of contexts to identify other issues that might act as barriers to student learning in science.

Implications for Teaching

Through exploring fifth-grade students' argumentative practices, this study provided significant implications to promote the development of competent argumentative practices in elementary science classrooms.

The major findings of the study were that students faced a number of difficulties in shifting their practice from a traditional orientation to a more argument-based orientation. The shift in learning orientation was not easily achieved and required time to occur. Table 5.1 shows that students spent sixteen weeks to develop a sophisticated understanding of argumentation, enhance the ability to use talk and writing as learning tools, engage in more complex and higher-order cognitive processes, and advance their understanding of the meaning of negotiation. The time taken in shifting the students' practice has implications for science classroom teaching and professional development. Experienced teachers are reluctant to give up their pedagogical strategies (Martin & Hand, 2009; Yip, 2001). These ways of teaching are "a part of teachers' repertoire of skills that have proven successful over time" (p. 35, Martin & Hand, 2009). As teachers are asked to implement argument-based inquiry approaches in their classrooms, they often expect to see significant outcomes of students' achievement in a relatively short time period. They usually give up and resist conducting this kind of approach in the beginning stage. However, although the teacher who participated in this study had a high level of implementation regarding incorporating an argument-based inquiry approach in his classroom, he still spent sixteen weeks helping students engage in creating a productive argumentation environment. Luft (2001) has further suggested that a long-term professional development program should be developed, applied, and assessed. Specific types of support that are necessary for a shift in pedagogy that would allow teachers to implement argument-based inquiry classrooms and strategies such as the combination of talk and writing should be considered for future study.

Another important outcome of this research was documentation of the shift in how talk and writing were used to construct scientific knowledge. Students from traditional classrooms usually view talk and writing as isolated tasks. However, when students used the two learning tools together to construct scientific knowledge, their high-order cognitive actions were facilitated and they came to take ownership of their learning. Building on those findings, teachers should design a series of iterating activities to engage students to use these two learning tools together during argumentative practice. Importantly, teachers should explicitly teach students how to use these two learning tools to debate, clarify, and revise their ideas and explanations at appropriate times. Students also should be encouraged and provided scaffolding with which to use these two learning tools to construct scientific knowledge right after they are taught how to use them. In addition, the sequence and simultaneity of using talk and writing should be considered in the design of curriculum materials. The use of talk and writing should not be assigned as isolated tasks. Rather, to help students develop conceptual understanding, the use of talk and writing should be embedded in argumentative practice. In doing so, students are encouraged to learn, realize the meaning of negotiation, and take ownership for their learning based on the context.

Implications for Future Research

Grounded in interactive constructivism and language as a learning tool, this study involved a sixteen-week investigation of elementary school students' argumentative practices while learning two units. A number of claims were made and evidence was provided to suggest that these students were able to demonstrate competent argumentative practice when given time, scaffolding, and opportunities for practice. Six core components of argumentative practice and five patterns of the use of talk and writing were identified to provide suggestions for designing more educative pedagogy and learning environments. The findings also raise questions and issues that require future research that will help educators and researchers better understand the complexities and barriers of argumentative practice embedded with talk and writing.

The purpose of this study was to explore the nature of argumentation and the patterns of talk and writing in an argument-based context. This study was conducted in a class taught by a teacher who had a high level of implementation using an argument-based inquiry approach. However, it is unknown whether the results of the study can be applied to other science teachers who have relatively less experience with an argument-based approach. What kinds of difficulties might these teachers face when they try to use these six core components to help students engage in successful argumentation? Does the combination of talk and writing still support students to learn science in these teachers' classrooms? Much work remains to be done to evaluate the application of the six core components in a wide range of contexts and at a larger scale to identify other issues that might be challenges to teachers and students.

Although the findings suggest that a combination of talk and writing might better support students' learning science and higher-order cognitive processes, future research with different groups of students and a wide range of contexts needs to be conducted to understand the impact of the combination of talk and writing on students' learning of science. The results of this current study do not allow one to conclude that a particular pedagogy, such as the simultaneous or sequential use of talk and writing, is the most effective way to promote the development of the knowledge and skills of argumentation and to craft written arguments. To understand and strengthen the effect of the combination of talk and writing, future research into the relationship between this kind of pedagogy and students' learning of science needs to be conducted.

A third issue that should be addressed in future research is the use of multi-model representations in argument-based inquiry classrooms. This study found that students came to use different models to represent, clarify, challenge, and defend their ideas during discussions. Using multi-model representations has value in argumentative practices. However, the use of multi-model representations was not the focus of this study, as it was not expected that students would use multi-model representations in argumentative practice. So far, much research related to writing as a cognitive model has emphasized individuals' cognitive processes and the text (e.g. Emig, 1977; Galbraith, 1999; Hayes, 1987; Klein, 1999; Scardamalia & Bereiter, 1986). Few research and writing models have focused on illustrating this kind of practice and cognitive process of using multi-model representations. How are different models connected to individual cognitive processes? What is the impact of different models on different argumentative practices such as presenting, critiquing, reflecting, and constructing? Are there some models that better facilitate students' learning science in argumentative practice than others in different science topics?

A fourth area of needed research deals with the realm of scientific reasoning. One of the central goals of science education is to promote epistemologically scientific reasoning in students (NRC, 1996, 2007). Researchers such as Bell and Linn (2000), Chinn and Malhotra (2002) and Songer, Kelcey, and Gotwals (2009) have suggested that evidence evaluation tasks hold promise for capturing a range of features of epistemologically scientific reasoning. The findings of this study have shown that students spent a majority of their time elaborating their ideas across two units by conducting different reasoning skills when they engaged in argument-based inquiry. Students also displayed their reasoning abilities by the end of the semester via using talk and writing simultaneously to clarify and deepen their scientific understanding. However, the area of reasoning was not the focus of this study. There is a need for extended research into how argumentative practice can advance students' reasoning abilities. Another question is how the combination of talk and writing can better support students to engage in an authentic reasoning environment.

Limitations of this Study

Several limitations of this study are presented to allow readers to gauge the usefulness and appropriateness of the findings for other settings. Limitations of the study were mainly derived from the research questions and methods.

First, this study was focused on how students develop their understanding of the nature of argumentation in an argument-based inquiry in which both talk and writing are used as learning tools as well as to identify the patterns of talk and writing that emerge as students construct understandings of scientific concepts. This study focused on only two learning tools: talk and writing. However, there are other useful learning tools that could foster students' science learning. For example, reading is a powerful learning mode in science classrooms (Holliday, Yore, & Alvermann, 1994). If reading was included in this study, the results and research methods, to a certain degree, might be slightly different. However, due to the necessity to narrow down the focus of this study and the lack of studies currently available which investigate the effect of the combination of these two learning modes, this study still provides insights into pedagogies and research methods that expand our limited knowledge of how to combine talk and writing to improve students' learning of science.

A second limitation is the size and variation of participants that could undermine how broadly applicable the results of this study may be. Only one class was included in this study due to the resources available and the nature of qualitative research. Additionally, no control group was included in this study with which to compare the results and interpretations; this study is therefore limited in its ability to attribute certain students' learning effects to other settings. However, even without a large number of participants and control groups, rich and detailed descriptions of the research site, participants, and findings might help readers make decisions about the study's application to other settings.

A third limitation involves the selection of students participating in semi-structured interviews and observation. While substantial work in previous studies has focused on optimizing participants in terms of gender, achievement levels in science, and verbal participation in class discussions, the current study did not sort students into groups based on those variables. In addition, many studies have designed situations in which students have regular group partners in order to observe conveniently. This study tried not to influence the teacher's usual teaching strategies and to reflect the real classroom environment. The current study did not ask students to stay in the same group over sixteen weeks. Selecting optimal participants in terms of achievement in science and verbal participation in discussions might therefore produce a better impact and different cognitive processes. Making students stay in the same group for the whole process may generate different results.

In addition, this research explored the nature of argumentation and the patterns of the use of talk and writing only in one semester over two units. If this study continuously observed this class for another semester across different units, the results might be different. Different components and patterns of the use of talk and writing might occur.

A final limitation of this study lies in the factor of the teacher. The teacher who participated in this study has a high level of implementation of an argument-based approach due to the scores of RTOP and previous years' observations. If this study was conducted in a traditional classroom, the results, to a certain degree, might be different due to other factors, such as familiarity with the argument-based approach and pedagogical content knowledge (Shulman, 1986, 1987). When viewing classroom life as synergistic, the learning effects caused by these factors are inseparable in this study.

APPENDIX A

INTERVIEW QUESTIONS

First Round Interview: Background and Conception of Science Learning

1. If someone asks you "What is science?" what will you tell him or her?
2. If someone asks you "How do you learn science?" what will you tell him or her?
3. Please describe for me something you know a lot about: plants. You can tell me anything you know about them. How do you know that you know so much about this subject?
4. Please describe something you learned in science class that helped you with something outside school. How did it help you?
5. Who or what helps you learn science in school? How does ____ help you learn science?
6. I heard your class talking about the word "claim" yesterday and today. "How would you describe to a 4th grader what a claim is?" I also heard your class talking about evidence. "How would you describe to a 4th grader what evidence is?" How do you come up with your claim when you learn about a topic (like plant investigation)? What sources do you take into account?
7. How do you come up with or create a claim? [if needed ask] What do you use to make your claim?
8. How do you get or find evidence for what you study in science class? [if needed ask] Can you think of any other ways to get or find evidence?

Second Round Interview: Retrospective Interview on Learning Science in a Classroom

1. I noticed in this science class that lots of people talk. Why do all of you talk so much in this science class?
2. I noticed in this science class that you sometimes write things in your journal. Why do you write things down in this science class?
3. When you write in your science journal, where do most of those ideas you write about come from?
4. What did you learn from this class? How?
5. How do you ensure that you know a concept?
6. How do you think talking in a group or in a class helps you understand a concept?
7. How do you think writing helps you understand a concept?
8. Does talking with your peers (classmates) influence your writing? How?
9. When your peers (classmates) have ideas that are different from yours, what do you think of their ideas?
10. What kinds of things do you take into consideration when you debate your claim and evidence?

Third Round Interview: Reflection on Learning Science from a Holistic View

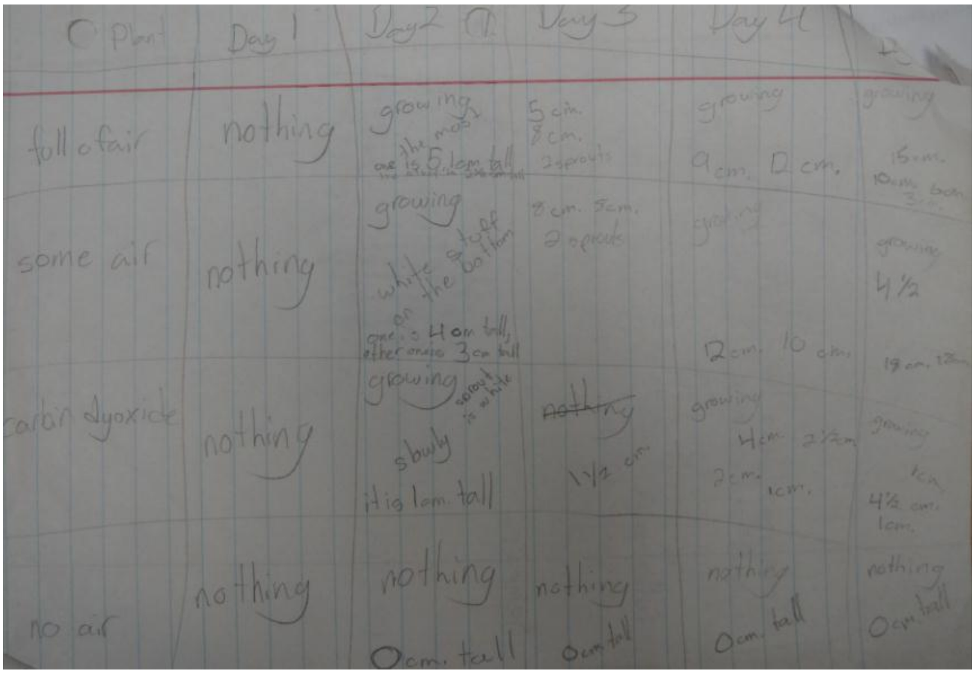
1. What have you learned in this unit?
2. Have you changed your views of the topic compared to the beginning of the unit? What did you change?
3. Did you change your claim at the end of this unit? Why?
4. Did you change your evidence at the end of this unit? Why?
5. How does talking in small groups or in a whole class help you understand the

concepts? Why do you think talking helps you understand the concepts?

6. How does writing help you understand the concepts? Why do you think writing helps you understand the concepts?
7. Does talking influence your writing? How? Why?

APPENDIX B

AN EXAMPLE OF ORGANIZING



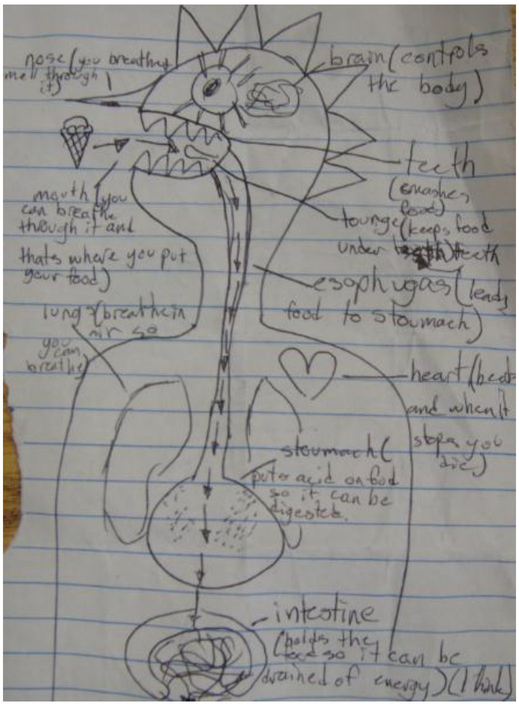
(Nolan writing sample, 9/30/2010)

APPENDIX C

AN EXAMPLE OF MULTI-MODEL REPRESENTATION

Claim: Our digestive system breaks down food for nutrients and energy.

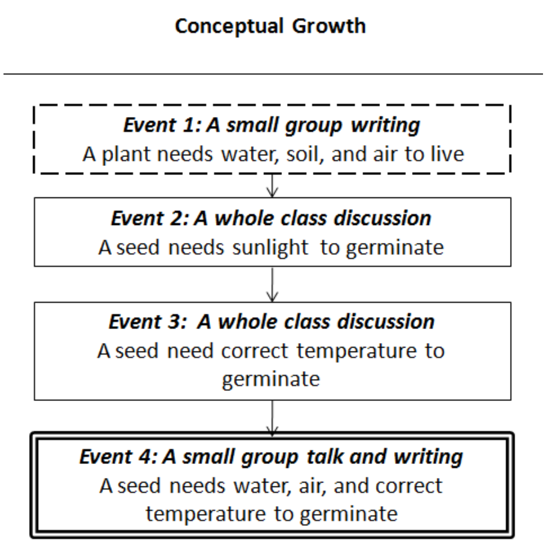
Evidence: The digestive system is a group of organs. The food is broken down by organs in digestive system. All of the parts in the digestive system affect the food in different ways. Some of these effects are longer then some are smaller. Food gets broken down into useful nutrients for your body. The organs and parts in your body that help break down the food are your teeth, tongue, saliva, esophagus, stomach, stomach acid, and your intestines.



(Nolan writing sample, 11/30/2010)

APPENDIX D

KNOWLEDGE CONSTRUCTION TRAJECTORY (KCT) EPISODE

Student Name	Kurt
Episode Number	Ecoysystem-Plant-Kurt_03
Unit	Ecosystem-Plant
Core concept related to this episode	Seeds need water, air, and appropriate temperature to germinate
Events included in this episode	*Event 1 (10/01/2010)-Small Group Writing* During Kurt's group writing for claim and evidence, Kurt claimed, "In order for a plant to live, it needs water, soil, and air." In Kurt's claim, three points which were scientifically incorrect needed to be addressed. First, this claim did not answer the research question—What do seeds need to germinate? Kurt confused seeds with plants in this claim. Second, soil is not a requirement for seeds to germinate. Third, Kurt did not consider that temperature is one important factor for seeds to germinate.
	Event 2 (10/04/2010)-Whole Class Discussion During this whole class discussion, Kurt understood the difference between seeds and plants. He knew his claim did not target the research question. In addition, Kurt thought seeds needed sunlight to germinate, although this concept is not scientifically correct.
	Event 3 (10/04/2010)-Whole Class Discussion Kurt clearly acknowledged that temperature is one important necessity for seeds to germinate.
	Event 4 (10/06/2010)-Small Group Writing Kurt wrote down his group's claim as "In order for a seed to germinate, its needs are water, air, and the correct temp."
The growth of concepts in this episode	

Description and Coding

Event 1 (10/01/2010)-Small Group Writing

Students were asked to write down their claim and evidence in a small group to answer the research question—What do seeds need to germinate? Kurt and his group member, Aaron, wrote down their claim and evidence as follows:

Claim: In order for a plant to live, it needs water, soil, and air. (claim _ accuracy; claim _

question)
Evidence: We know this because we ran tests. In the water test we found out that in the cup we gave it, it needed about 30 mL of water. At max, the cup held about 250 mL of water. In the air test, we found out that the plants need air like we do, but they don't take in carbon dioxide. Takes in carbon dioxide and breathes out the air that we breathe in. In the soil test, we found out that without soil, the plant would die faster. It doesn't need soil, but eventually after it has germinated and a plant starts growing, it will die faster, because it doesn't have anything to start its roots in. (evidence _ reasoning; evidence _ sufficiency; evidence _ data)

In their claim, three points were scientifically incorrect. First, the claim did not target the research question. That is, the research question focused on the needs of a seed to germinate, not a plant. Second, soil is not a requirement for a seed to germinate. Third, Kurt's group did not consider correct temperature as one of the requirements for a seed to germinate.
In their evidence, Kurt's group did not explain the reason why a seed needs water to germinate. They just noted their test data without any explanation. In addition, they did not explain the reason why a seed also needs air and soil to germinate. They just rephrased the claim again in their evidence.

Two reasons can be provided for why Kurt's group did not produce evidence with rich reasoning. First, they did not clearly know what they investigated. Their writing showed that they tried to answer the question "What do plants need to live," rather than "What does a seed need to germinate?" Second, and more important, they did not know how to reason, explain, and interpret their data as evidence.

Event 2 (10/04/2010)-Whole Class Discussion

The class required each group to present their claim and evidence. After each group presentation, students were asked to provide questions to critique each group's claim and evidence. After the first group's presentation, the teacher asked the question, "Kalie, is the question what do plants need or what do seeds need?" (clarification). After T's question, the students realized that they should just focus on seeds, not on plants.

Another question came up after the first group presentation. T initiated the question "Seeds need air, water, sunlight or darkness to germinate. Agree, disagree?" (elicit idea). Students started to argue with each other. Mary responded, "I disagree with darkness because not every single plant needs darkness." However, other students posed different positions.

Olivia	Yeah, you can't take away both of them.	Defense	Simple
Teacher	Am I arguing that they're going to get one or the other? Or am I saying possibly it's not even a need that we have to talk about?	Focus	
Kurt	Possibly, but you know, if you take away sunlight it has to be in darkness. If you take away darkness it has to be in sunlight.	Challenge	Conditiona
Teacher	But we're talking about needs, Kurt. Is it a need to germinate, as in if you take it away, it won't germinate?	Challenge	Focus
Kurt	You can't exactly take it away.	Defense	Simple

In this conversation, Kurt thought seeds need at least sunlight or darkness because the earth provides it already. Other students supported his idea. For instance, Blair also speculated, "Because everywhere there's gotta be an amount of sunlight or an amount of darkness." (challenge_ conditional). However, those students' ideas were not consistent with current science concepts that suggest sunlight and darkness are not necessary for a seed to germinate; correct temperature is one of the requirements.

Event 3-Whole Class Discussion

Then, one critically important moment occurred during the following conversation. Emma provided her group's experimental result that showed seeds germinated in both sunlight and darkness (challenge _ compare). This result brought students to think differently about the requirements of a seed to germinate.

Blair	Well, I'm really confused like, same with Olivia. Because if you don't put it in sunlight, and you don't have to put it in… It's not a requirement to put it in sunlight and it's not a requirement to put it in darkness, where do you put it? Because everywhere there's gotta be an amount of sunlight or an amount of darkness.	Challenge	Conditional
Teacher	Wait, so Journey says it has to have sunlight. Because?	Elicit idea	
Journey	Because it gives off warmth.	Support	Evidence
Kurt	But that means it doesn't need sunlight, it only needs the warmth from it.	Elaborate	
Olivia	It doesn't need sunlight; it just needs heat.	Support	Simple

Journey came up with the idea that seeds don't need sunlight or darkness, they just need warmth. The reason why Journey came up with this idea was because Blair mentioned an important key word, "requirement," which triggered Journey to postulate that seeds don't need sunlight or darkness, they just need warmth. Kurt elaborated on the idea following her conversation.

After this conversation, other students were still confused about the idea that seeds don't need sunlight or darkness to germinate. Kurt tried to convince other students of his idea.

Kurt	Really, when a seed is under the soil, it doesn't get any sunlight; depending on how far deep you put it, it can't get to the sunlight but it can get to the heat the sunlight's producing.	Support	Evidence
Blair	But if I am understanding Olivia's question… but still, if you put it in the place, and it's either sunlight or darkness, then it's fine - you just have to get warmth.	Support	Evidence
Kurt	Yeah, and it doesn't matter which one you put it in, you just have to give it heat.	Elaborate	
Adam	You can put it anywhere.	Support	Simple

Event 4 (10/06/2010)-Small Group Writing

After each group's presentation, students were asked to modify their claim and evidence based upon class discussion. Kurt's group revised their claim and evidence as follows:

Claim: In order for a seed to germinate, its needs are water, air, and the correct temp. (claim _ accuracy; claim _ question)

Evidence: We figured this out by testing these items: water, soil, air, sunlight, food, darkness, fertilizer, and temp. Water, air, and temp, when we took these items away the plants died. When we took the others away, no change. So in conclusion, without water, air, and temp, the plant won't germinate. It needs water because without it, it will be dehydrated and dry up. It needs air because if you took air away, it would suffocate and slowly when it took in air there would be none to take in so eventually it would die. If you took away heat (the correct temp) it would overheat and wouldn't germinate well. (evidence _ reasoning; evidence _ counterevidence; evidence _ sufficiency)

In the revised claim, Kurt and his group member make their claim more consistent with scientific concepts as well as target it to answer the research question.

In the evidence, Kurt's group integrated what they talked about in class. Not only did they provide sufficient evidence to support the claim, they also accurately explained why seeds need water, air, and correct temperature to germinate. Additionally, they provided counterevidence to make their evidence stronger.

Analytical Notes

This episode occurred when students generated their claim and evidence, presented and defended them to their peers, and finally revised them.

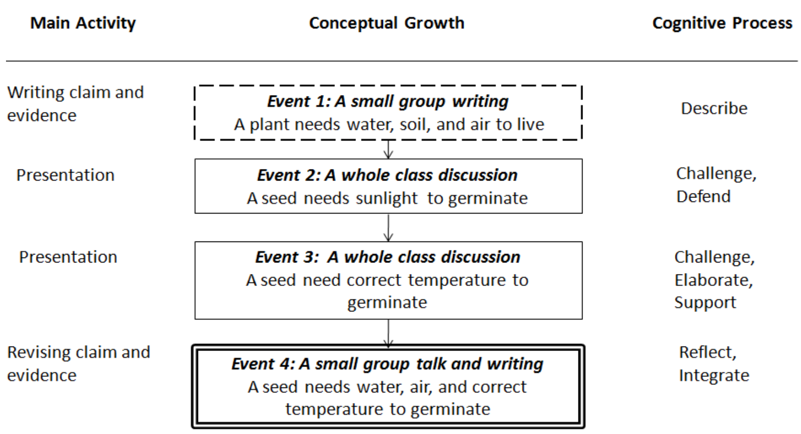
This episode can be broken down into several different parts. In the beginning, Kurt's writing showed that he did not consider sunlight to be one of the requirements for a seed to germinate. However, after listening to other groups' presentations, he shifted his thinking to the belief that sunlight is one of the requirements for a seed to germinate, although this is not scientifically correct. He joined his own ideas to the class argument, proposing, "If you take away sunlight it has to be in darkness. If you take away darkness it has to be in sunlight" (challenge _ condition).

Later, Emma mentioned her group's experimental results, which showed that seeds germinated in both sunlight and darkness. These results made students think about the requirements for seeds to germinate. Consequently, Journey came up with the idea that sunlight gives seeds warmth. Building on Journey's idea, Kurt elaborated, "It doesn't need sunlight, it only needs the warmth from it" (elaborate). After Kurt acknowledged that warmth is a requirement for a seed to germinate, he tried to persuade other students to believe his ideas.

This series of conceptual growth might have been caused by several reasons. First, Kurt realized how his claim and evidence lacked compared to other groups'. Second, continuous challenge, clarification, and critique caused conceptual disequilibrium for Kurt. In order to defend his ideas, he had to provide stronger reasons to defend. Finally, he found a way out to bring his concepts into equilibrium again due to strong reasoning.

After the whole class discussion, Kurt had to reflect on what he debated in class. He had to integrate and write up the concepts discussed in class. This process made him reflect on the conversation, synthesize the ideas, and translate those ideas to his own ideas. The revised writing showed his conceptual growth and argument development.

Role of talking and writing in this episode

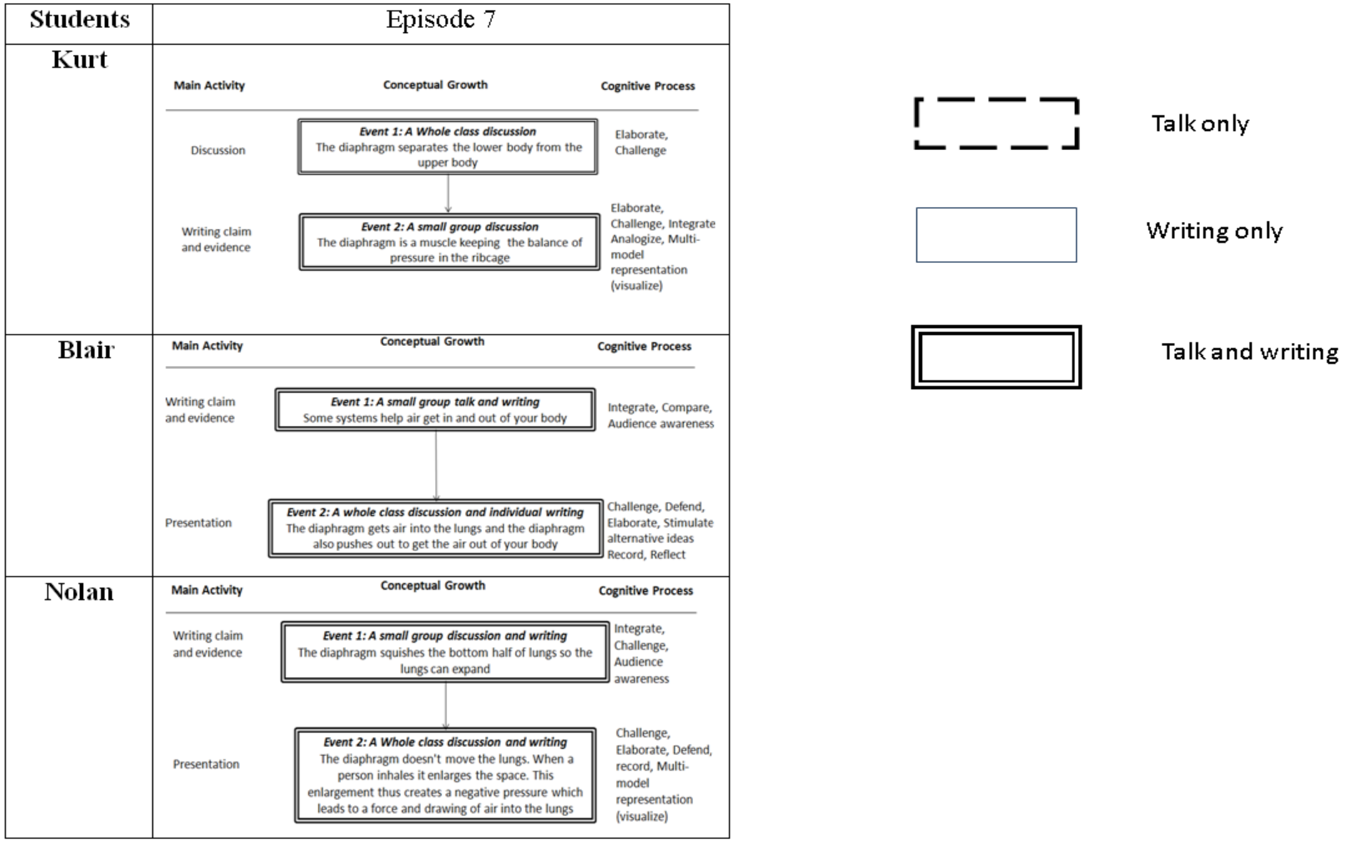


APPENDIX E

THREE STUDENTS' KNOWLEDGE CONSTRUCTION TRAJECTORY (KCT) FOR ECOSYSTEM AND HUMAN BODY SYSTEM

Students	Episode	Main Activity	Conceptual Growth	Cognitive Process
Kurt	Episode 1	Experiment	*Event 1: A small group test* What does a seed need to germinate?	Recode
		Writing result of the experiment	*Event 2: A small group writing* A plant needs water to germinate	Describe
	Episode 2	Writing claim and evidence	*Event 1: A small group writing* A plant needs water to live	Describe
		Presentation	*Event 2: A Whole Class discussion* A plant needs water, air, and soil to germinate	Share, Express
		Revising claim and evidence	*Event 3: A small group writing* A plant needs water, air, and soil to live	Record, Report
	Episode 3	Writing claim and evidence	*Event 1: A small group writing* A plant needs water, soil, and air to live	Describe
		Presentation	*Event 2: A whole class discussion* A seed needs sunlight to germinate	Challenge, Defend
		Presentation	*Event 3: A whole class discussion* A seed need correct temperature to germinate	Challenge, Elaborate, Support
		Revising claim and evidence	*Event 4: A small group talk and writing* A seed needs water, air, and correct temperature to germinate	Reflect, Integrate
Blair	Episode 1	Experiment	*Event 1: A small group test* Do seeds need sunlight or darkness to germinate?	Express
		Presentation	*Event 2: A whole class discussion* Seeds need sunlight and/ or darkness to germinate	Report
	Episode 2	Writing claim and evidence	*Event 1: A small group discussion and writing* Some seeds need sunlight and/or darkness to germinate	Organize
		Presentation	*Event 2: A whole class discussion* Seeds need correct temperature to germinate	Challenge, Elaborate, Compare
		Revising claim and evidence	*Event 3: A small group talk and writing* seeds need air, water, and the correct temp to germinate, but seeds do not need sunlight or darkness to germinate	Reflect, integrate
	Episode 3	Answering teacher question	*Event 1: Teacher's question* Humans get all of their energy from the Sun?	Express
		Discussion on the question	*Event 2: A whole class discussion* We get part of our energy from sun, but also part from food	Challenge, Defend, Elaborate
		Writing own idea	*Event 3: Individual writing* Humans do not get energy from the Sun.	Reflect, Compare, Integrate
		Discussion on the question	*Event 4: A whole class discussion* Humans indirectly get energy from the Sun	Challenge, Defend, Elaborate
Nolan	Episode 1	Experiment	*Event 1: A small group test (individual writing)* Do seeds need air to germinate?	Organize Recording, organize
		Presentation	*Event 2: A whole class discussion* Seeds need air to germinate	Report
	Episode 2	Presentation	*Event 1: A whole class discussion and individual writing* Seeds need air to germinate	Express, Compare
		Writing claim and evidence	*Event 2: A small group writing* seeds need air, water and correct temperature to germinate	Reflect, Integrate
	Episode 3	Presentation	*Event 1: A whole class discussion* Seeds need air, water, and correct temperature to germinate	Challenge, Elaborate, Compare
		Writing claim and evidence	*Event 2: A small group discussion and writing* Seeds need air or carbon dioxide, water, with the right temperature, to germinate.	Reflect, Integrate, Audience awareness

Students	Episode 4	Episode 5	Episode 6
Kurt	Main Activity / Conceptual Growth / Cognitive Process Answering teacher question — *Event 1: A Whole class discussion* Do human get energy from the sun? — Elaborate, Compare Explaining his idea — *Event 2: Represent ideas on the whiteboard* Human indirectly get energy from the sun — Multi-model representation, Organize	Main Activity / Conceptual Growth / Cognitive Process Test — *Event 1: Individual writing (pre-test)* Your body digestive it and turn it into energy — Describe Analyzing data from experiment — *Event 2: Small group discussion and writing-focus on analysis* The human body system work together by an order — Compare, Integrate, Organize Writing claim and evidence — *Event 3: Small group discussion and writing* Our digestive system breaks down food for nutrients and energy — Integrate, Challenge, Stimulate alternative ideas	Main Activity / Conceptual Growth / Cognitive Process Presentation — *Event 1: A Whole class discussion* Our digestive system breaks down food for nutrients and energy — Express, Challenge, Defend, Stimulate alternative ideas Writing claim and evidence — *Event 2: Small group discussion and writing* Digestive system affects the food in different ways — Reflect, Integrate, Multi-model representation (visualize), Challenge, Defend, Audience awareness
Blair	Main Activity / Conceptual Growth / Cognitive Process Test — *Event 1: Individual writing (pre-test)* When the food goes into the mouth, it goes down your throat then into your abdomen then it goes through a process — Describe Analyzing data from experiment — *Event 2: Small group discussion and writing* Food goes through different parts of digestive system — Integrate Writing claim and evidence — *Event 3: Small group discussion and writing* In order for the digestive system to work, it needs multiple different tasks in your body — Integrate, challenge, Stimulate alternative ideas, Multi-model representation, Defend	Main Activity / Conceptual Growth / Cognitive Process Presentation — *Event 1: A whole class discussion and individual writing* In order for the digestive system to work, it needs multiple different tasks in your body — Challenge, Defend, Elaborate, Stimulate alternative ideas, Record Writing claim and evidence — *Event 2: A small group discussion and writing* The digestive system uses other systems to work — Reflect, Integrate, Challenge	Main Activity / Conceptual Growth / Cognitive Process Presentation — *Event 1: A whole class discussion and individual writing* Digesting is a process that makes the food break down — Challenge, Defend, Elaborate, Stimulate alternative ideas record, Compare Writing claim and evidence — *Event 2: A small group talk and writing* The digestive system uses other systems of organs to work — Reflect, integrate, Compare
Nolan	Main Activity / Conceptual Growth / Cognitive Process Presentation — *Event 1: A whole class discussion* Seeds need air or carbon dioxide, water, with the right temperature, to germinate — Challenge, Defend, Elaborate Writing own claim and evidence — *Event 2: Individual writing* Seeds need air, water, the correct temperature, and energy to germinate — Reflect, Integrate, Compare	Main Activity / Conceptual Growth / Cognitive Process Test — *Event 1: Individual writing (pre-test)* It goes in your body and you digestive it and get rid of it — Describe Analyzing data — *Event 2: Small group discussion and writing-focus on analysis* The human body system work together by an order — Analyze, Multi-model representation. Integrate Writing claim and evidence — *Event 3: Small group discussion and writing* Our digestive system breaks down food for nutrients and energy — Challenge, Compare, Stimulate alternative ideas, Organize	Main Activity / Conceptual Growth / Cognitive Process Presentation — *Event 1: A Whole class discussion and individual writing* Each part of digestive system works together by breaking down the food for the next part of the system — Challenge, Elaborate, Defend, Record, Multi-model representation (visualize) Revising claim and evidence — *Event 2: Small group discussion and writing* Our digestive system breaks down food for nutrients and energy — Reflect, Integrate, Multi-model representation, Challenge, Audience awareness



Notes: Broken line boxes indicate that the target students only used talk as learning in the event; solid line boxes indicate that the target students only used writing as a learning tool in the event; double line boxes indicate that students used both talk and writing as learning tools in the event.

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