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Dual processing and discourse space: exploring fifth grade students' language, reasoning, and understanding through writing

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DUAL PROCESSING AND DISCOURSE SPACE: EXPLORING FIFTH GRADE STUDENTS' LANGUAGE, REASONING, AND UNDERSTANDING THROUGH WRITING

by

Sae Yeol Yoon

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

December 2012

Thesis Supervisor: Professor Brian Hand

ABSTRACT

The purpose of this study was to explore the development of students' understanding through writing while immersed in an environment where there was a strong emphasis on a language-based argument inquiry approach. Additionally, this study explored students' spoken discourse to gain a better understanding of what role(s) talking plays in the development of understanding through writing. Finally, the study proposed a new concept of Discourse Space, which enabled researchers to improve their understanding of the characteristics of the development of student cognition through writing, and of the roles talking plays in cognitive development through writing.

This study was guided by the research question: What patterns of the development of fifth grade students' cognition over time emerge in their private and public negotiations under a teacher who is ranked as a low-level implementer of the SWH approach? This question was divided into two sub-questions: (a) Throughout a unit, Ecosystems, what patterns emerge regarding the development of six fifth grade students' understanding through writing, and b) What patterns of the development of Discourse Space emerge through talking in three different contexts. In order to answer these questions, this qualitative research employed a generic qualitative study.

Twenty-one fifth grade students participated in this study, and six students were purposefully selected through which to further investigate the development of an understanding of science through private negotiation while immersed in a language-based argument inquiry approach. Major data sources included students' writing samples, informal conversations with the teacher, researcher's field notes, and classroom videos. Additionally, the teacher's modified RTOP scores and semi-structured interviews were used to deepen the contextual understanding of the learning environment and the teacher's instructional performance. The data analysis was conducted by utilizing discourse analysis of writing and talking.

The results showed (1) students' low level of engagement in evaluation impacted their reasoning and use of sources for making meanings, as well as their understanding of the topic. Compared to the results of a previous study, students' complexity of reasoning was relatively less developed, and similarly students' use of reflective sources was generally observed relatively less often. (2) The teacher and students in this study engaged in limited public negotiation, which focused more on articulating than on evaluating ideas. The limited public negotiation that was represented by the dialogical patterns in this study cannot support the development of understanding through writing or the practice of the roles of constructor and critiquer, which play a core function in the comprehension of scientific practice.

This study has several implications for teacher education and research. Teacher education needs to be centered more on how to encourage students' engagement in the process of evaluation, since this plays an important function not only in the development of understanding, but also in providing opportunities to perform the roles of both constructor and critiquer. Teachers can use writing as an argumentative activity to encourage or foster students' engagement in the process of evaluation or critique. Additionally, this study provides insight into the importance of the learning environment in which the teacher and students create and develop; this learning environment needs to provide not only opportunities but also demands for students to engage in both constructing and critiquing ideas.

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Graduate College
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CERTIFICATE OF APPROVAL

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PH.D. THESIS

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To my family

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ABSTRACT

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CHAPTER ONE

INTRODUCTION

Language for Learning

A guiding concept for language and science is that without language, there is no science (Norris & Phillip, 2003). Drawing from Social Constructivism originated from Vygosky's (1962, 1978) theory including social development and zone of proximal development (ZPD), many researchers view language as the fundamental tool for social interaction that plays a crucial role in the development of cognition[1] (Vygotsky, 1934; Wertch, 1991; Lave & Wenger, 1991; Mortimer & Scott, 2003). However, this does not mean that language is important only because it functions as the medium with which to exchange ideas. Language also functions as the fundamental resource for the development of cognition (Klein, 2006). Therefore, learners not only engage in social interactions that involve in the use of language, but also are participating in dynamic cognitive processes that use language as a resource for the development of cognition.

When only one of these functions is emphasized, students experience a limited use of language in the science classroom. For example, if language is only stressed as a communication tool, students may view it as simply a tool to deliver information, and thus they do not integrate the diverse functions of language. That is, they focus exclusively on the scientific content of the information being delivered by language. Meanwhile, if language is only viewed as a source for the development of cognition, students may tend to construct an individually-contextualized understanding of the natural world that may make it difficult for them to adopt a more generalized and scientifically acceptable understanding. Therefore, when using language as a learning

[1] In this study, I defined cognition as the mental processes involved in constituting and retrieving knowledge. These processes include thinking, knowing, remembering, understanding, applying, analyzing, synthesizing, evaluating, judging, and problem-solving. They engage multiple levels of brain functions and relate to people's language, perception, and representation.

tool (Norris & Phillips, 2003), importance is placed on creating a learning environment in which these two functions are balanced and valued. In this environment, students engage in language-based activities for learning language, learning about the language of science, and learning science though language (Norton-Meier, 2008). With this in mind, this study aims to explore students' use of language while immersed in an environment where there is a strong emphasis on the various functions of language in a science classroom.

Construction vs. Critique and Argumentation

In the U.S., science education from K to 12 has undergone several reform efforts, and contemporary reform efforts have emphasized the importance of learning science as inquiry (e.g. American Association for the Advancement of Science, 1990; National Research Council [NRC], 1996). Influenced by Constructivism, such an inquiry approach stresses that students' active engagement in learning in some ways parallels the process by which scientists construct knowledge (NRC, 1996). In this trend, fostering students' ownership of ideas (Voltz & Damiano-Lantz, 1993; Yoon, Bennett, Mendez, & Hand, 2010), or authorship (Ford, 2008a), is considered the essential goal of the teaching and learning of science.

However, the authors of the National Science Education Standards have established that the goal of science teaching is to have students learn scientific knowledge with understanding (NRC, 1996, p.26). They articulate that students' active engagement in the learning process cannot assure understanding of science will be achieved. They argue that active engagement in the learning process is not enough to assure students' understanding of science, and therefore that the inquiry approach does not automatically lead to student cognition. In discussing this issue, Ford (2008a) emphasized the importance of knowing how to hold claims accountable, in contrast to prevailing constructivist ideas that highlight student authority, or ownership, to construct knowledge as scientists do. To highlight the significance of accountability, Ford (2008a) further argued that "construction without appropriate critique would not result in the creation of new scientific knowledge" (p. 410). Critique, therefore, should also be involved in students' cognitive processes and social interaction for learning science.

From this point, many scholars have emphasized the role of argumentation in teaching and learning science. Since the concept of argumentation was introduced in the field of science education in 1998, over half of the published research in the discipline (59.5%) has included key aspects of argumentation (Erduran, Ozdem & Park, 2011). With this in mind, a model of argumentation has been proposed as part of the teaching and learning in the science classroom as the learning of scientific inquiry and literacy (Erduran & Jimenez-Aleixandre, 2008; Kelly & Takao, 2002; Zohar & Nemet, 2002).

Cavagnetto (2010) categorized research on using argumentation for learning science into three orientations: a) immersion in science for learning scientific argument (immersion), b) learning the structure of argument to learn and apply scientific argument (structure), and c) experiencing the interaction between science and society to learn scientific argument (socioscientific). He concluded that although these three orientations shared the fundamental idea that argument is particularly important for helping students become literate in the discourse of science, "only the immersion orientation appears to fully capture the culture, including the epistemic nature of science that is embedded in scientific practice" (p.352). Therefore, Cavagnetto believes that when immersed in an argument-based inquiry approach, students can develop scientific cognition. In this regard, this study examined students' use of language for the development of scientific cognition while immersed in an argument-based inquiry approach.

Development of Cognition through Writing

Along the same lines, there is a growing amount of research that argues that writing plays a crucial role in argumentative practice (Hand, Gunel, & Ulu, 2009; Kelly

& Takao, 2002; Keys, 1999; McDermott & Hand, 2010; McNeill, Lizotte, Krajcik, & Marx, 2006; Sandoval & Millwood, 2005; Wallace, 2006). However, most studies in argumentation have focused on the final products of writing and the value of argument and argumentation rather than on exploring the process of students' development of cognition over time (Sampson, Grooms, & Walker, 2011). For example, Kelly, Chen, and Prothero (2000) found that writing helped postsecondary oceanography students establish a more thorough understanding of the argument structure. McNeill (2009) investigated the effect of embedding written argument structure in the classroom.

The limitation of these studies is that they are unable to account for the process of students' development of understanding through writing. Furthermore, they are unable to answer in what ways writing as argumentative practice can help the development of cognition. In this regard, there is a need to explore how writing as learning—as an epistemological tool and as argumentative practice—helps to develop student cognition beyond being simply a tool to understand the structure or components of written arguments.

Writing is not just speech written down (Emig, 1977; Olson, 1994). Beyond the act of producing written texts, writing involves the use of multiple cognitive processes (Hayes & Flower, 1980; Bereiter & Scardamalia, 1987; Galbraith & Torrance, 2004; Kellogg, 2006). Previous research on cognitive processes in writing, however, overemphasized the importance of the explicit thinking process in writing and hence treated text production processes as a relatively passive component of the writing process (Galbraith, 2009, p.24). In response to this, Galbraith (2009) proposed a dual-process model of writing as discovery that involved a knowledge-retrieval system and knowledge-constituting system.

Drawn from dual-process theory (Stanovich, 1999; Evans, 2008), Galbraith's (2009) dual-process model of writing successfully explains how writers create coherent knowledge by engaging not only in memory processes, but also in a synthetic process. In both processes, students use language as a representation of meanings that emerged through cognitive processes. In the knowledge-retrieval process, representing meanings is limited to explicit representation of knowledge in separate fixed units, if we can model the mind as a network that consists of connections of multiple units (see Connectionists' account for human cognitive architecture). However, in the knowledge-constituting process, representing meanings also involves the implicit representation of knowledge in the connections between units.

From this viewpoint, the knowledge-constituting process needs another process for making representation explicit based on feedback from interactions not only between content in the working memory and the writer's conceptual knowledge in the long-term memory, but also between the produced texts or linguistic resources in the working memory and the writer's linguistic knowledge in the long-term memory. While engaging in this additional process, writers, therefore, have opportunities to evaluate, critique, and synthesize meanings, which enables them to constitute a new knowledge, helping the development of cognition. This study examined the characteristics of the development of students' understanding through writing while immersed in an argument-based inquiry approach.

Purpose of the Study

The purposes of this study were 1) to explore the development of students' understanding through writing while immersed in an environment where there is a strong emphasis on a language-based argument inquiry approach, 2) to gain a better understanding of what role(s) talking plays in the development of cognition through writing, and 3) to propose a concept of Discourse Space that is defined as representing meanings that emerge in discourses in a particular learning context, and which serve as the learning resources that improve learners' experiences of scientific discourse, knowledge and practice.

This study explored how students develop their cognition over time while engaging in written argumentation as a private negotiating process and spoken argumentation as a public negotiating process. By closely examining students' development of cognition, this study aimed to achieve a better understanding of what roles talking plays in the development of cognition through writing, and what features of argumentative practice influenced the development of student understanding through both talking and writing. This provides insights into the ways students use cognitive and linguistic resources that emerge in private and public negotiation and how they transform these cognitive and linguistic resources for the development of their understanding through writing.

Another purpose of this study was to propose a concept of Discourse Space, building on a pilot study (Yoon & Hand, 2012). Drawn from cognitive psychological accounts, this newly proposed concept enables us to improve our understanding of the characteristics of the development of students' cognition through writing, and of the roles of talking in cognitive development through writing. By exploring the transformation of Discourse Space that emerged in fifth grade students' private and public negotiations over time, this study attempted to attain a more sophisticated comprehension of how students' cognition, as it emerged in their written discourse, had developed by interacting with the contents and contexts that their spoken discourse exhibited.

Research Questions of the Study

1) What are the characteristics of developing discourse space demonstrated by fifth grade students' private and public negotiations when an argument-based inquiry approach was implemented?
    a) Throughout a unit, Ecosystem, what patterns emerge regarding the development of six fifth grade students' understanding through writing?

i) How does the reasoning complexity that emerged in the writing samples change over time?

ii) How does students' use of sources of meaning that emerged in the writing samples change over time?

b) What are the patterns of the development of discourse space through talking in three different contexts?

i) What are the patterns of the development of discourse space as the teacher frame Discourse?

ii) What are the patterns of the development of discourse space as students engage in class discussion initiated by teacher reading?

iii) What are the patterns of the development of discourse space as students engage in group presentation?

Rationale of the Study

A growing number of scholars have studied argumentation in science classrooms as the core practice of teaching and learning science (National Research Council, 1996; Osborne, MacPherson, Patterson, & Szu, 2012; Cavagnetto, 2010). However, only a small amount of research has emphasized written argumentation. According to Erduran, Ozdem and Park's (2011) recent review of literature on argumentation, only 15 % of argumentation studies focused on written argumentation. Additionally, most of those studies of written argumentation have focused on the final products of writing and the value of argument and argumentation rather than on exploring the process of students' development of cognition over time (Cavagnetto, 2010; Sampson, Grooms, & Walker, 2011).

Students' engagement in written argumentation is not isolated from contexts in which they are immersed in argumentative practices involving the use of diverse modes of language. In this sense, by only exploring written argumentation, there are inherent limitations to understanding how students engage in the learning experience through argumentation to develop their understanding of science. Therefore, there is a need to explore the development of student understanding through writing while immersed in an environment where there is a strong emphasis on a language-based argument inquiry approach.

Writing is not simply transcribed speech (Emig, 1977; Olson, 1994). Beyond an act of producing written texts, writing involves the use of multiple cognitive processes (Hayes & Flower, 1980; Bereiter & Scardamalia, 1987; Galbraith & Torrance, 2004; Kellog, 2006). However, understanding how students engage in multiple cognitive processes and how those processes help the development of cognition has been rarely discussed in argumentation literature. Drawing from dual process theories, I explored cognitive processes that students might experience when they engaged in writing activities by examining the characteristics of the development of students' understanding through writing while immersed in an argument-based inquiry approach.

In this study, I explored fifth grade students' cognitive development when an argument-based inquiry approach was implemented by a teacher who had scored at a low level on the Reformed Teaching Observation Protocol (RTOP). The teacher's interactions create or hinder opportunities for student learning and the epistemic nature of what might be learned (Lemke, 1990). Many researchers have explored high-level teachers measured by diverse observation tools such as RTOP to attain a better understanding of the characteristics that good science teaching practice exhibits. However, at present, little research has investigated how low implementing level teachers use argumentation in their science classes, and how students experience argumentative practices in those science classrooms.

Despite the importance of argumentation for learning science, many studies have reported that elementary school students usually have difficulty in interpreting data to generate evidence, coordinating evidence and claims, and debating their claims in public (Cavagnetto, Hand, & Norton-Meier, 2009; Martin & Hand, 2009). Furthermore, many elementary teachers often encounter difficulties when implementing argumentation in their science classes (Newton, Driver, & Osborne, 1999; Osborne & Dillon, 2008). In this regard, this study might provide a more sophisticated understanding of how argumentative practices were implemented in elementary science classes, and of how students experienced the development of understanding through private and public negotiation; this would provide an expansion of preliminary studies that explored these characteristics as revealed in high-level teachers.

This expansion helped to build a new notion, Discourse Space, which this study aimed to propose. Discourse Space is defined as the space that consists of diverse resources that students used when engaged in scientific practice for the development of their understanding of science within a certain context. The notion helps to account for the cognitive and linguistic dynamic in using language in a science classroom. Since language functions not only as the fundamental resource for the development of cognition, but also as a medium to represent meanings, there was a need to apply a theoretical lens to explore how students develop their cognition through using language by considering both the epistemic nature of language and its representative nature. However, current studies have tended to focus separately on only one of these two natures (ref). With this in mind, this study proposed a new notion, and might be used as a touchstone to help teachers and researchers create a more sophisticated understanding of learning language, learning the language of science, and learning through language.

Overview of the Study

This chapter has provided the background and purpose of this study, focusing on language for learning, argumentation, and writing. The research questions and the rationale of the study have also been stated.

Chapter Two provides a review of the literature related to this study. I first discuss existing literature that explains and supports practices of scientific literacy, science argumentation, and writing. I then discuss the theoretical framework that grounds this study. Since this study explores students' use of language, it approaches language both in terms of its use as an epistemic and as a representational tool, and proposes a new concept of Discourse Space to deepen an understanding of students' use of language for learning. With this understanding, this chapter explores the three shifts suggested by Klein that can be observed in students' use of language, knowledge construction, and thinking; dual-processing theory provides the theoretical foundation for this exploration.

I begin Chapter Three with my epistemological and ontological view of the world. I then define and explain my research design, and provide a description of the context including the school, participating teacher and her instruction, students' ideas about the unit, participants, and data sources for this study. Additionally, I discuss the ways in which the data was analyzed, and verify the trustworthiness of this study in terms of establishing credibility, transferability, dependability, and confirmability.

Chapter Four is a presentation of the findings as they address each research question. I present findings regarding the complexity of reasoning and the use of sources for making meanings that emerged in students' writing. Two major findings are identified from students' writing: (1) all six fifth grade students' reasoning had developed over time, and (2) students' use of sources for making meanings had changed over time. Then, I present findings regarding students' engagement in talking as public negotiation. One major finding is identified from students' talking: (1) students as participants in discourse had limited opportunities and demands to engage in dialogical interactions. Overall, the findings suggest that students had limited opportunities and demands to engage in type 2 processing not only for the development of understanding, but also for practicing the roles of both constructor and critiquer.

Chapter Five summarizes and examines the findings of this study. The chapter ends with a discussion of the study's implications for teaching, future research, and limitations.

CHAPTER TWO

LITERATURE REVIEW

In this chapter, the researcher explores scientific literacy as a goal of science education, the immersion in argumentation for achieving that goal, and writing as argumentative and scientific practice. Next, the researcher develops a framework for exploring students' use of language. Additionally, this chapter reviews the use of language as both an epistemic and a representational tool, and introduces a new concept to deepen the understanding of how language is used for learning. Finally, drawing from cognitive psychology, the chapter explores how students can build canonical scientific knowledge from their fuzzy understanding, and what this shift implies for their learning of science.

Scientific Literacy as a Goal of Science Education

Since the term *scientific literacy* was introduced in the late 1950s, it has been widely claimed to be a desired outcome of science education. Many attempts have been made to define it; however, there is not a common consensus of what it means. Bybee (1997) asserted that scientific literacy is a broad concept encompassing many historically significant educational themes that have shifted over time. Laugksch (2000), in reviewing the history of science education to locate the historical and contemporary meanings of scientific literacy, showed that the term included a number of different assumptions, interpretations, conceptions, and perspectives regarding what it means, what introducing the concept should achieve, and how it is constituted. He suggested that the term may be no more than a useful slogan to rally educators to support more, and better, science teaching. If we accept this claim, then "the term *Scientific Literacy* is simply *science education* in general" (DeBoer, 2000, p.582).

If the goals of science education can be couched in terms of literacy, what is the goal of scientific literacy education? Historically, there has been a major tension between two views regarding the goal of science education: training the future scientist as the producer of scientific knowledge and educating the future scientist as a critical consumer of scientific knowledge (Osborne, 2007). According to Roberts (2007), this tension is still occurring in the discipline. However, current reform efforts are aimed primarily at promoting the scientific literacy necessary for all young people growing up in our society, whatever their career aspirations or aptitudes (Millar & Osborne, 1998; Osborne, 2007). DeBoer (2000) also concluded that "scientific literacy has usually implied a broad and functional understanding of science for general education purposes and not preparation for specific scientific and technical careers" (p.594). Therefore, it is currently agreed that scientific literacy for all young people is the major goal of science education (cf. National Research Council, 1996; Rutherford & Ahlgren, 1990).

Despite broad agreement regarding the goal of scientific literacy education, discourses concerning what the term means, what introducing the concept should achieve, and how it is constituted seem to keep diverging. Nevertheless, science educators have gradually agreed that any promotion of science literacy should empower people to be literate in the discourse of science (Yore & Treagust, 2006). Based upon this agreement, Norris and Phillips (2003) defined a new approach toward scientific literacy, and moved beyond the argument about sloganeering by distinguishing between the fundamental sense of science literacy (i.e. the ability to read and write) and its derived sense (to be knowledgable about, learned and educated in, science) (Smith, Loughran, Berry, & Dimitrakopoulos, 2012).

Norris and Phillips (2003) provided an interpretation of the concept that allows its application to the mandatory levels of K-12 schooling and beyond, and which applies to all students. Their interpretation of these two interacting senses of science literacy is supported by many science education reform documents and studies. They explored how literacy in its fundamental sense is central to scientific literacy, arguing that within this sense people need to be proficient in scientific language and thinking. In relation to the derived sense of science literacy, they argued that people need to understand the nature of science, its "big ideas," and the relevance of the interactions among science, technology, society, and environment.

Based on Norris and Phillip's (2003) interpretation of this concept, it appears that in current research focusing on scientific literacy the fundamental sense of the term has been highlighted more often than the derived sense. This does not mean, however, that only the fundamental sense is crucial in promoting learners' scientific literacy, since the derived sense also plays a central role in being literate in the discourse of science. As Gee (2005) has highlighted, there exists a symbiosis between the two senses of science literacy in which the fundamental sense influences the achievement of the derived sense. However, Yore and Treagust (2006) have commented that although "it was a sincere belief that achievement of the fundamental sense of science literacy will lead to achievement of the derived sense of science literacy. This symbiosis still lacks evidence" (p.311). Therefore, there is a need to explore potential ways to create this symbiosis.

Immersion in Argumentation for Creating Symbiosis

From the argument that scientific literacy is agreed as the major goal of science education, argumentation is understood as a core practice to achieve that goal (National Research Council, 1996; Osborne, MacPherson, Patterson, & Szu, 2012; Cavagnetto, 2010). Furthermore, argumentation has been positioned as it should be taught and learned in the science classroom as part of the learning of scientific inquiry and literacy (Erduran & Jimenez-Aleixandre, 2011; Erduran & Jimenez-Aleixandre, 2008; Kelly & Takao, 2002; Zohar & Nemet, 2002). Throughout his broad literature review examining the nature of argument as intervention in the science classroom, Cavagnetto (2010) categorized literature on argumentation for learning science into three orientations: a) immersion in science for learning scientific argument (immersion), b) learning the structure of argument to learn and apply scientific argument (structure), and c) experiencing the interaction between science and society to learn scientific argument (socioscientific).

These three orientations shared the fundamental idea that argument is particularly important for helping students become literate in the discourse of science. Basically, all three orientations highlight students' ability to read and write about science or science-related issues, which can be seen as fundamental scientific literacy. However, Cavagnetto (2010) argued "only the immersion orientation appears to fully capture the culture, including the epistemic nature of science that is embedded in scientific practice" (p.352). In other words, it might be unclear how the other two orientations could lead to students' scientific literacy in a derived sense, allowing them to understand the nature of science, the big ideas of science, and the fundamental elements of scientific practice.

As a counterargument, some might contend that understanding the structure of argument through engaging in inquiry can help students understand the nature of science (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). Researchers adopting this position argue that this structure orientation helps students engage in argumentation through which they can construct their own arguments, defend their knowledge claims, and critique peers' claims with evidence. Throughout this engagement, students may be able to improve their argumentation skills and understanding of the structure of argument, which they can then transfer to diverse situations. However, Cavagnetto (2010) argued that this orientation cannot provide students with opportunities involving "other elements of scientific practice such as controlling variables, experimental trials, error, data transformation, and interpretation of data" (p. 351).

Ford (2008a) also claimed that the goal of argument instruction in the context of scientific literacy is the transfer of an understanding of scientific practice, rather than the transfer of an understanding of the structure of argument. This understanding of scientific practice is possible through participation in science, and language plays a central role in the participation in scientific practice because it requires and develops abilities such as metacognition and critical reasoning. Moreover, language is fundamental because it drives the epistemic nature of science and captures its culture; both inform interpretation and knowledge construction related to science (Cavagnetto, 2010).

Ford (2008b) further highlighted scientific practice by articulating how a ‘grasp of practice’ served as a reasoning resource for inquiry and the national/cultural contexts/conditions associated with the nature of scientific understanding. With this phrase, Ford (2008a) emphasized the role of construction and critique as the culturally-based and discipline-specific patterns of interaction in a science community. Especially, he argued for the importance of critique in scientific practice because:

> Scientists who are successful are so because they learn how to critique their own knowledge claims as their peers do. In contrast to the positivist vision, a dialectic of construction and critique characterizes scientific reasoning involved in generating new knowledge claims. Construction without appropriate critique would not result in science. (Ford, 2008a, p.410)

With this in mind, students need to engage in scientific practice through language practice in order to improve their scientific literacy. Implementing argumentation as a core scientific practice helps students to grasp a tool for understanding the epistemological aspect of disciplinary knowledge (how we know) and for understanding the content itself (what we know) (Ford, 2010). However, not all argumentation approaches can help to fully capture culture, including the epistemic nature of science that is embedded in scientific practice. Only the immersion-orientated argument approach can do this (Cavagnett, 2010).

To grasp scientific practice, students need to learn not only how to play the role of constructor, but also how to play the role of critiquer in the community (Ford, 2008a). The goal of argument instruction in the context of scientific literacy is not the transfer of an understanding of the structure of argument, but rather the transfer of an understanding of scientific practice. Therefore, the immersion-orientated argumentation approach, in which students can play both roles and play them as they interact to ground authority (as constructors) and accountability (as critiquers) in science, can help to create the symbiosis necessary for them to achieve both a fundamental *and* a derived sense of scientific literacy. Although not many current instructional designs include explicit instructional attention to critique (Ford, 2008a), the Science Writing Heuristic approach (Hand & Keys, 1999) is one possible approach to help students achieve both a fundamental *and* a derived sense of scientific literacy.

The Science Writing Heuristic (SWH) Approach

The Science Writing Heuristic (SWH) approach is a language-based argument approach that provides students with inquiry activities, enabling them to play the role of both constructor and critiquer while immersed in argumentation (Hand, 2008; Keys, Hand, Prain, & Collins, 1999). The approach requires students to "pose questions, make claims about their inquires, use the data in logical ways to structure reasoned evidence to support their claims, examine what scientists and others say about their investigations, and then to stand back and reflect on what they have learnt from inquiries" (Hand, 2008, p. ix).

The SWH approach encourages students to use different forms of language in various settings as they engage in scientific inquiry throughout private and public negotiation processes where they participate in scientific practice to support scientific literacy. By emphasizing language experience in the science classroom, students have opportunities to engage in cognitive processes and social interactions to improve their scientific reasoning. Through opportunities for talking, students engage in scientific practice that provides them with epistemic learning experience by playing the roles of both constructor and critiquer on a communal level. Through opportunities for reading, they engage in private negotiation by interpreting texts to explore current version of scientific knowledge and to create new scientific knowledge based on scientific reasoning that appeals to the behavior of nature through explicit connections. Through opportunities for writing, students participate in writing-to-learn tasks that incorporate the need to access canonical scientific knowledge and, thus, to engage the nature of science and its epistemologies and reasoning strategies as a framework for building understanding (Hand, Prain, Lawrence, & Yore, 1999).

Previous research in the SWH approach has indicated its efficacy for promoting student conceptual understanding (Keys, Hand, Prain, & Collins, 1999), cognitive engagement (Grimberg & Hand, 2009), and understanding of science questions, claims, and evidence (Wallace, Hand, & Plain, 2004; Martin & Hand, 2009). The effectiveness of the SWH is consistent with the principle that metacognition is important for learning through writing (Bangert-Drowns et al., 2004; Georghiades, 2004; Hand & Prain, 2006). Furthermore, the approach is understood as an attempt to integrate the expressive features of human thought and language with the denotative features of authentic science texts (Klein, 2006). In this regard, this study utilized the SWH approach to provide students with a learning environment where there is a strong emphasis on language while immersed in an argument-based inquiry approach that helps them engage in dynamic cognitive processes and social interactions to support the fundamental sense of scientific literacy and to lead to the derived sense of scientific literacy by playing the role of both constructor and critiquer.

Writing as Argumentative Practice

Writing researchers have argued that writing is a learning tool because writers engage in ongoing cognitive practices including producing, organizing, monitoring, reviewing, and reflecting on their ideas through interactive negotiation between dispositional and linguistic knowledge (Bereiter & Scardamalia, 1987; Galbraith, 1999;

Hayes & Flower, 1980; Kellogg, 2008; Keys, 1999; Klein, 1999). Throughout these dynamic cognitive processes, writers can enhance both their writing skills and their knowledge of a topic as required by the writing task. However, topic knowledge is not restricted to substantive content knowledge of the particular topic (Norris & Phillips, 2003). Instead, it also includes cognitive skills such as critiquing and critical thinking that enable writers not only to accomplish the writing task, but also to transfer their knowledge into different situations. Thus, following the line of argument from the writing to learning movement, writing can be viewed as a process that helps to develop writers' conceptual understanding of topic, cognitive skills, and writing skills (Klein, 2006).

Writing also operates as an epistemological tool for learning, and enables students to construct and critique links between classroom activities, conceptual understandings, and their expression (Hand & Prain, 2012). Student-generated written discourse entails new knowledge they have constructed, choices they make for generating ideas and language, and reasoning they use for creating, reviewing or reflecting ideas and language (Klein, Boman, & Prince, 2007). Moreover, Rivard and Straw (2000) found that "writing is an important discursive tool for organizing and consolidating rudimentary ideas into knowledge that is more coherent and well-structured" (p.586). Therefore, student texts are not simply transcribed speech, but rather act as written discourse that is built upon a theory of speech (Olson, 1994) where writing is viewed as the creation of texts that explore relationships among ideas (Klein, 1999).

In addition to its use as a learning and epistemic tool, there is a growing amount of research that argues that writing plays a crucial role in argumentative practice (Hand, Gunel, & Ulu, 2009; Keys, 1999; Sandoval & Millwood, 2005; Wallace, 2006). However, most of the studies in argumentation have focused on the final products of writing and on the value of argument and argumentation, rather than on exploring the process of students' development of argumentative practice over time (Sampson, Grooms, & Walker, 2011). The goal of argument instruction in the context of scientific literacy is not to provide students with opportunities to learn the structure of argument as a genre of language. Students need to learn how scientific knowledge has developed through argumentation as a core scientific practice. In this regard, Ford (2008) emphasized the transfer of an understanding of scientific practice, rather than the transfer of an understanding of the structure of argument. Therefore, there is a need to explore in what ways writing can help students engage in scientific practice to support scientific literacy, and ultimately in what ways writing can help the development of students' understanding of science.

Understanding Writing as Scientific Practice

Importantly, to this point there has been a lack of studies accounting for the process of students' engagement in scientific practice through writing. In other words, current literature on writing has focused little attention on answering in what ways writing as argumentative practice provides students with opportunities to engage in scientific practice through which they play the role of both constructor and critiquer. Beyond thinking of writing as a tool of text production for recording data, communicating findings, presenting understanding, and reviewing previous claims, there is a need to understand writing as an argumentative practice that helps students engage in scientific practice for the development of understanding through writing. In this light, I first reviewed writing models, and then further examined the potential of Galbraith's (1999) model of writing to portray writing as argumentative practice.

Most of the current research on writing shares the fundamental concept of understanding the writing process as a cognitive action. Flower and Hayes (1980) proposed a model of cognitive processes in order to develop a cognitive account of writing. Their model proposes three main processes involved in planning, translating, and reviewing that operate through a monitor function that allows access not only to these three activities but also to the writer's long-term memory. Following these studies (Flower & Hayes, 1980, 1984; Hayes & Flower, 1986), Bereiter and Scardamalia (1987) characterized the essential difference between novice and more expert writing as a contrast between a knowledge-telling and a knowledge-transforming model of writing. In a knowledge-telling model, the resulting text reflects the structure of knowledge in the writer's own mind, modified only as much as is required to conform to the conventions of the genre in which he/she is writing. In a knowledge-transforming model of writing, developing an explicit representation of the rhetorical problem as a hierarchy of goals and subgoals is involved, and the active transformation of content in order to satisfy these goals is required.

Galbraith (2009) argued that these models put forward by Bereiter and Scardamalia (1987) separated thinking from language production, and went on to explain that thinking largely relates to content formulation. The formulated content is retrieved from memory, so that the contents are treated by already stored constructs in long-term memory. Even in the knowledge transforming model, although content is formulated by reorganization and modification by problem translation in the content problem space, content knowledge that enters the space is understood as pre-existing constructs in long-term memory. Therefore, these two models cannot explain a mechanism for the process of constructing new knowledge claims through writing. Given the fact that, in scientific practice, construction and critique of claims are two aspects of the same reasoning resource (Ford, 2008b, p.151), Galbraith (2009) argued that these models cannot account for students' engagement in scientific practice for the development of understanding through writing.

Galbraith (2009) therefore proposed a model of writing as "knowledge constitution." In his proposed model, he used two basic principles of Connectionist processing: a) the synthesis rather than retrieval of content and b) the implicit rather than explicit organization of knowledge. This model provides an account of how dispositionally guided text production could lead to the development of a writer's understanding. In this model, therefore, content is not stored and waiting to be retrieved. Instead, it is synthesized depending on the activation of the network as a whole, if we can model the mind as a network consisting of nodes linked by differently strengthened connections. Thus, content is stored implicitly on the basis of the strength of the connections between nodes. That is, text production can be seen as a synthetic process, resulting in the construction of new knowledge claims.

Importantly, students engage in two different evaluation processes through writing based on: a) feedback from content in working memory to the writer's disposition, and b) feedback from produced texts and linguistic resources in working memory to the writer's linguistic disposition. These evaluating processes play a crucial role in students' engagement in scientific practice. First, they perform a similar function to the critique component involved in public negotiation. When scientists present arguments for a new knowledge claim, peers seek errors in the inferential chain that forms the explicit connection to nature's behavior (Ford, 2008a). While participating in writing activities for knowledge constitution, students individually engage in cognitive processes for developing ideas that are responsible for producing two different feedbacks that function as the evaluation of the inferential chain represented by written texts. Fundamentally, these processes involve not only constituting new knowledge claims, but also critiquing their own knowledge claims. Therefore, evaluation that emerges in writing as knowledge constitution serves as a process of critique.

Second, in the development of understanding through writing, students also engage in articulation of individual reasoning patterns that are keys to participation in scientific practice. Scientific accounts for natural phenomena do not lie on the level of individual reasoning, and scientific knowledge is explicit, public, and a product of a community. However, writing as a knowledge constituting process helps students engage in a process of implicit and explicit evaluation with respect to their current knowledge claims to complete writing tasks. Such evaluation helps them improve their reasoning of science, and through ongoing writing activities they can begin to articulate their individual reasoning patterns. In this regard, writing helps students engage in scientific practice for the development of understanding.

Theoretical Framework for the Study

Language as an Epistemic and Representational Tool

Research has introduced the concept of multiple functions of language. Linell (1998) conceptualized language in basically two ways, as system or structure, or as discourse, practice or communication. In the former, language is a collection of linguistic resources. From this perspective, students might learn the structure of the language of science as abstract or decontextualized meanings. In the latter, a language can be seen as part of the communicative or cognitive practices of actors' discourse-in-contexts. In this view, languages are constructive and constitutive of the ways we act and think in the world, and in how we perceive and conceive of the world. This epistemic function of language that Linell (1998) illustrated is specified more clearly in Gee's (1999) view of language function.

Gee (1999) viewed the major function of language not as communicating information, but rather as a tool to: a) support performance of social activities and social identities and b) support human affiliation within cultures, social groups, and institutions. With these functions, Gee (1999) argued that people "always and simultaneously construct or build [the] reality" in which they are situated by engaging in talking and writing (p.11). In other words, the meanings of signs (words, actions, objects, artifacts, symbols, texts, etc.) are situated in embodied experience. Meanings are not general or decontextualized. Whatever generality meanings come to have is discovered bottom up from embodied experience (Gee, 2003). In his view, language serves as an ontological tool to construct and reconstruct a self or identity in a social context by interacting with others including cultures, communities, institutions, and so forth.

Likewise, Halliday (1993) viewed language as a 'system of meanings.' Similar to Gee's (1999) perspective, Halliday (1993) argued that when people use language to make meanings, they do so in specific situations, and the form of the language that they use in discourse is influenced by the complex aspects of those situations. However, Halliday emphasized three different functions of language (called metafunctions). He argued that language is used to organize, understand, and express our perceptions of the world and of our own consciousness (ideational metafunction); language is used to enable us to participate in communicative acts with other people, to take on roles, and to express and understand feelings, attitudes, and judgments (interpersonal metafunction); and language is used to relate what is said or written to the rest of the text and to other linguistic events (textual metafunction). In his view, language also serves as an epistemic tool to build logical and experiential stories, relationships between participants, and linguistic artifacts as meanings.

I adopted and modified multiple functions of language into educational settings, especially the science classroom, for analyzing discourse that students created in that setting. In this sense, I first viewed language as an epistemic tool to build experience, knowledge, identity, and discourse of science when participants engage in scientific practices. Second, I viewed language as a representational tool to portray not only the culture of science, but also the experience, understanding, and identities of students while attempting to become full participants in the discourse of science. These two functions, which were closely related and intertwined, enabled this study to further explore the process of making meanings for the development of cognition through students' engagement in public and private negotiation.

Language and Discourse Space

People use language with two different functions. However, there is no hierarchical relation between the two functions, and both play a crucial role in teaching and learning science. Although it might be the chicken or the egg dilemma, in this study, I assumed that languages are fundamentally seen as representational since an epistemic function of language is only possible when language has the representational nature. Moreover, representation is one of the fundamental and generative activities, and is at the heart of the human experience (Enyedy, 2005). Representation is the act of highlighting aspects of our experience and communicating them to others and ourselves. Therefore, language as representation, not only as function, is an entity consisting of a form fused with a meaning. Based on this inherent nature of language, representation, it is possible for this study to explore the development of cognition as revealed in student-generated spoken and written discourse.

However, generating a representation goes well beyond simple encoding. The meanings represented by language are not always equally accessible to and understood by all readers (as broad meanings) since meanings developed from language are influenced by readers' prior knowledge and cognitive capacity to use meaning-making resources, and are strongly influenced by the contexts in which meanings are represented and communicated. Furthermore, language includes all types of representation of meanings that are used for communication, and is thus inevitably multimodal (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001). Thus, this study approached students' use of language in terms of discourse in which students make and develop meanings through discursive practices for the development of cognition, and therefore proposed a notion of Discourse Space as a guiding lens.

Discourse Space is defined as representational meanings that students used when engaged in scientific practice for the development of understanding of science within a certain context. In this notion, I used a concept of space to describe the physical and psychological realm or expanse in which discourses were created when students experienced the development of their understanding of science as they engaged in the discursive practice of responding to scientific practices. The core feature of space is flexibility, and thus Discourse Space can be viewed as flexible in terms of size and shape when developing through time.

I borrowed a concept of Discourse from Gee (1990) by referring to "Discourse" with a capital "D." Discourse in this sense is a combination of saying-writing-doing-being-valuing-believing, and is always more than just language. According to Lave and Wenger (1991), scientists know implicitly how to act appropriately and how to participate in scientific practice. If we can frame scientific practice as a culture, much of what people know culturally is implicit (Rogoff, 2003). Therefore, scientists create Discourse as a combination of saying-writing-doing-being-valuing-believing in their scientific practice. If students' understanding with respect to nature can be held accountable, then classroom discourses can be created whereby students in science classrooms can have experiences that parallel scientists' Discourse. In other words, the science arguments that student generate are not just about their ideas, but about how their ideas compare to what is currently known and how they can align their views with existing, accepted explanations (Hand, 2008). In this regard, I attempted to explore students' use of language (discourses) through the lens of Discourse Space to attain a better grasp of the development of students' understanding through private and public negotiation.

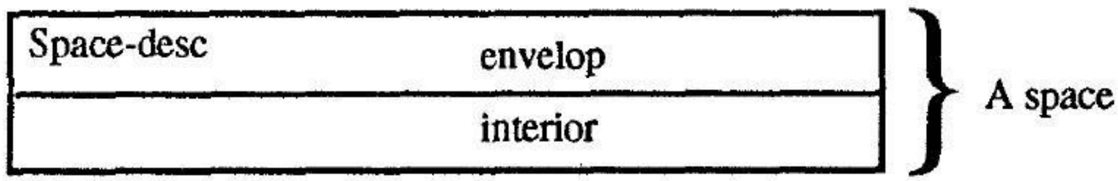
The notion of Discourse Space that originated from linguistics has rarely been discussed in the field of education. Therefore, the definitions used in linguistics will be briefly introduced. Then, a revised version of Discourse Space will be presented for this study to help attain a better comprehension of students' use of language for the development of understanding through private and public negotiation.

Discourse Space as a Place for the Development of Understanding

From a linguistics perspective, Moulin (1995) defined *discourse space* as a pragmatic form of context which is used to structure knowledge contained in a discourse. He viewed context as fundamentally pragmatic since his basic assumption was that "a human agent naturally used contextual information because she could not manipulate or communicate knowledge without positioning herself relatively to that knowledge" (Moulin, 1995, p.89). In other words, he stated that context involved the relationship established between locators and the speech acts they perform.

Moulin (1995) viewed discourse space as distinct from a mental space as identified by Fauconnier (1994). According to Moulin (1995), a mental space is manipulated by an agent's reasoning mechanisms while discourse space is generated by an agent in order to structure the information that she will transmit when performing speech acts. When producing or understanding a discourse, an agent evoked, created or modified a mental model that composed discourse space. Discourse spaces can also be evoked, created or modified by agents who try to understand a discourse. Therefore, exploring discourse space will help to provide a better understanding of cognitive processes that students might engage in while participating in scientific discourse. In this regard, I adopted Moulin's (1995) pragmatic interpretation of the notion of context, which can be used to model the architecture of discourses.

In representing this concept Moulin (1995) presented the architecture of discourses as a space that was a topological entity composed of an envelope and an interior. The envelope delimited the interior, and was the interface between the interior and the exterior of the space. Graphically, Moulin (1995) represented the space as a double rectangle (Figure 2-1). A space's envelope and interior were regions containing other spaces and elements such as concepts and conceptual graphs used by an agent to describe the real or imaginary worlds in which she is involved. This set of related spaces was called discourse space, structured the discourse content, and eventually built the architecture of discourse, which could be thought of as a cognitive map built on the basis of the concepts transferred by locators when they perform their speech act.



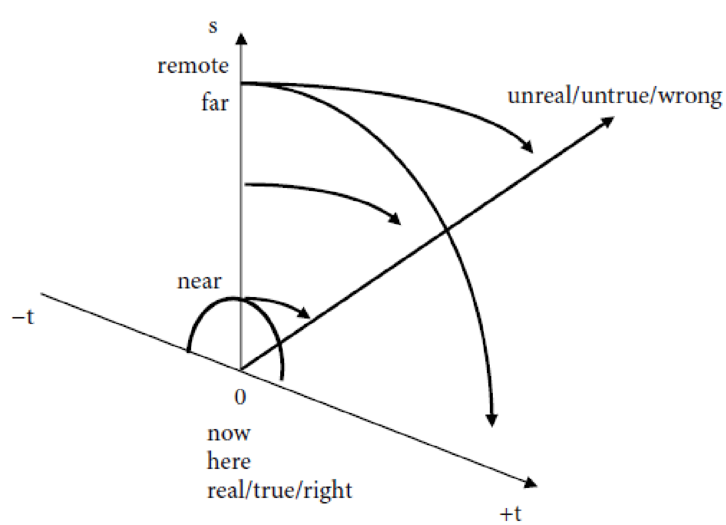
Source: Moulin, 1995, p.91

Figure 2-1 A representation of Discourse Space

However, Moulin's (1995) representation of discourse space has limitations that need to be considered when examining complex classroom discourses and the discourse processing that occurs in science classrooms. Furthermore, his model was designed to display the architecture of discourse, so mental space cannot be presented by this model. Therefore, another model is needed for this study.

Chilton (2005) offered another model that characterized discourse processing. Based on Cognitive Linguistics, he proposed a notion of discourse space using coordinate geometry and vector spaces. Chilton's (2005) discourse space attempted to model some fundamental properties of human discourse. His major focus was on discourse that was situated, embodied, and speaker-oriented, rather than on non-situated linguistic knowledge. His discourse space model consisted of an abstract three-dimensional space which used geometric vectors to represent not only spatial locations but also movements. In addition, the geometric vectors were used to represent semantic configurations that could be viewed as being derived from spatial concepts. His model of discourse space took the strength of the concept of mapping, with this mapping helping to provide a potential mathematical clarity for presenting his material. Influenced by the discourse representation of Kamp and Relye (1993), mental space by Fauconnier (1994), metaphor by Lakoff and Johnson (1980), and iconic pictorial diagram by Langacker (1996), he investigated the applicability of coordinate vector geometry for the representation of discourse processing.

As a result, he proposed discourse space as representing the speaker's consciousness of his/her position in space. This is not an objective position in space, but rather a cognitive position as constructed in the mind of the speaker. This discourse space was triply deictic, having three axes: spatial, temporal, and modal. In the spatial axis (s-axis), a scale of relative distance from the deictic origin was examined. The temporal axis (t-axis) gave relative temporal distance from the origin in two directions: past (-t) and future (+t). The role of the modal axis (m-axis) was to reflect what seemed to be the case for all utterance, namely that speakers entertain meta-representations and give them a valuation in terms of the subjective truth value. Integrating three axes in the coordinate geometry and vector spaces helped to characterize discourse processing. Figure 2-2 shows the geometry and vector space integrated by three axes.



Source: Chilton, 2005, p.91

Figure 2-2 Discourse Space, Time-Space-Modality Perspective

Chilton's (2005) discourse space also focused on characterizing discourse processing, and was helpful for representing what was going on as a particular discourse occurred. However, his discourse space aimed to investigate viewpoint shifts (or alternations) in discourse space. Although representation of discourse space enabled modeling of the phenomena of mental spaces by mapping cognitive position in space as constructed in speakers' minds, the current study did not explore viewpoint shifts. Therefore, it was difficult to use his model in the context of this study.

In summary, this study adopted a conceptualization of discourse space from Moulin (1995) and Chilton (2005), and described Discourse Space as a set of representations of meanings that participants in discourse develop while engaging in a particular practice, and which serve as a resource that improves their experiences of discourse, knowledge, and practice. Differing from previous models, I also considered Fauconnier's (1994) mental space by exploring cognitive and linguistic resources that emerged in Discourse Space. Although this study did not aim to represent Discourse Space as a model, a three dimensional representation drawing from Chilton's (2005) model seemed to have more potential to represent the architecture of dynamic classroom discourses. However, differing from the model of discourse space by Chilton (2005) that describes viewpoint shifts in limited discourses, this study focused more on systematic presentation of dynamic changes of cognitive and linguistic resources while students engaged in diverse science classroom discourses and practices over time.

I adopted Bernstein's (1999) concept of vertical and horizontal discourses to schematically visualize the Discourse Space. Bernstein defines the differences between vertical and horizontal discourse as follows:

> …a vertical discourse takes the form of a coherent, explicit, and systematically principled structure, hierarchically organized, as in the sciences, or it takes the form of a series of specialized modes of interrogation and specialized criteria for the production and circulation of texts, as in the social sciences and humanities…[In contrast], a horizontal discourse entails a

> set of strategies which are local, segmentally oranized, context specific and dependent, for maximizing encounters with persons and habits. (Bernstein, 1999, p.159)

Drawing from his perspective, the initial stage of Discourse Space could be seen as the horizontally expanded space. In this phase of Discourse Space, students started generating and sharing a variety of resources for discursive practice. Depending on the students' own interests, individual students participated in and contributed to developing the horizontal discourse. However, this type of discourse was contextualized, segmentally organized, and localized, so that it might be difficult for participants to construct scientifically-reasonable knowledge claims. Despite this limitation of horizontal discourse, the emergence of horizontally developed Discourse Space was crucial since it played a role in generating and sharing resources for the development of cognition. Figure 2-3 shows this type of Discourse Space.

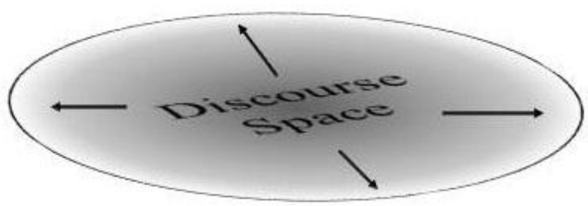


Figure 2-3 Horizontally developed Discourse Space

On the other hand, the vertically developed Discourse Space always emerged after the horizontal discourse occurred. Students as participants in discourse started to elaborate, evaluate, and advance ideas based upon resources that they generated and shared in the phase of horizontal discourse. Students might add new information and resources in this vertical stage, but the major goal of this vertical discourse was to build a coherent story that had a systematically principled structure, or was hierarchically organized. In this light, the discourse that students built could reach the level of Discourse of science that took the form of a series of specialized modes of interrogation and specialized criteria for the production and circulation of texts. Figure 2-4 shows the vertically developed Discourse Space.

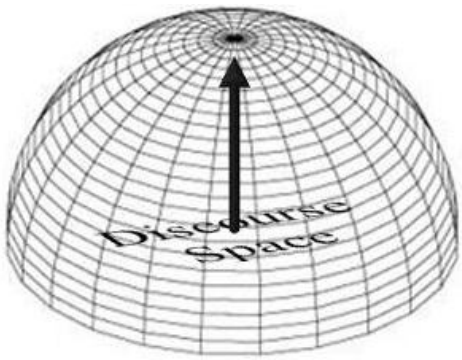


Figure 2-4 Vertically developed Discourse Space

This conceptualization of Discourse Space was different from Moulin (1995) and Chilton (2005) even though it shared the fundamental ideas of discourse and space. In summary, I viewed Discourse Space as representing meanings that students used while engaged in scientific practice for the development of understanding of science within a certain context. From Berstein's (1999) notions, the process of developing Discourse Space was understood via the movement from the horizontal to the vertical discourse stage. When students engaged in the vertical discourse stage by analyzing, evaluating, elaborating, and advancing the ideas that were generated and shared at the horizontal discourse stage, the Discourse of science might take place. However, these previous studies did not offer any explanation of what components influenced the changes or development of the Discourse Space that students created. I argue that dual-process theory might serve as a potential concept to explain how students moved from the horizontal to the vertical discourse.

Dual-Process Theory and Scientific Reasoning

The dual-process theory attempts to account for human cognitive actions such as reasoning, judgment, decision-making, and social cognition (Evans, 2003, 2006, 2008, 2010; Stanovich, 2009, 2010). There is a wide range of ways to describe two processes, such as implicit and explicit, heuristic and analytic, automatic and controlled, domain specific and domain general, associative and rule-based, and so forth (See table 1 Evans, 2008, p. 257). Stanovich (1999) suggested the more generic terms type 1 processing processes and type 2 processing processes, and these terms have become popular (Evans, 2010). However, these labels seem to connote that the two processes in dual-process theory map explicitly to two distinct brain systems, and imply that it is refereed as a singular system (Stanovich, 2011). Moreover, systems in the brain should be viewed as plural systems, or a set of systems. Therefore, in this paper I described dual processes as type 1 and type 2.

According to the heuristic-analytic theory of reasoning (Evans, 1984, 1989; Evans, Over, & Handley, 2003; Evans, 2006, 2008), the type 1 process (*heuristic/intuitive processing*) generates selective representations of knowledge. The processes are fast, automatic, and belief-based. Reasoning in type 1 processes (type 1 reasoning) is contextualized, and biases in reasoning can occur in these processes. The processes selectively focus attention on task features that appear relevant, also introducing relevant prior knowledge (Evans, 2008). Type 2 processes (*analytic/reflective processing*), on the other hand, derive inferences or judgments from representations generated by type 1 processes. Reasoning in type 2 processes (type 2 reasoning) is related to hypothetical thinking that must include the processes of evaluation[2], and is, therefore, slow, explicit, and can be understood as abstract and decontextualized reasoning. In other words,

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[2] The concept of evaluation is largely used in psychology while the concept of critique is frequently used in philosophy.

whereas type 1 processes use heuristic processes that generally supply hypotheses within contextualized reasoning, it is the task of type 2 processes to critically evaluate them and, if need be, to modify or replace them. However, this does not mean that type 2 processes do not produce any biases. Type 1 processes can omit logically relevant information or include logically irrelevant information, and serve to deliver content for type 2 to work with the representation. If representations generated by type 2 processes are not considered as irrelevant information due to limited cognitive capacity, resources, and contexts, type 2 processes are also able to maintain the bias. In brief, type 2 processes are slow, explicit, and sequential, but can also include bias.

This raises the question of how type 1 reasoning relates to type 2 reasoning and what cognitive processes are similar between these two processes. These two processes are independent since preconscious heuristic processes continuously supply content to consciousness for analytic/reflective processing (Evans, 2008, 2011). However, this does not mean that these two processes have a simple sequential structure. For example, type 1 reasoning sometimes competes with type 2 reasoning (Verschueren, Schaeken, & d'Ydewalle, 2005), although the two do not compete as parallel processes. Type 1 processes may contain bias, and influence the shaping of analytic thinking in type 2 processes since the contextualized representations generated in type 1 are delivered by type 2 processes. In other words, type 1 processes may generate the initial mental models which influence initial responses, inferences, or decisions regarding tasks or topics the student is currently facing.

In this study, a mental model is described as the representations that people form of hypothetical possibilities (Evans, Over, & Handley, 2003). Of import is that the mental model we describe in this paper is epistemic, representing states of belief and knowledge. This epistemic mental model encodes a degree of conditional belief that one event will lead to the other. The model may go further and represent the fact that this belief is rooted in a causal linkage (Evans, 2008). That is, the epistemic mental model requires explicit representation of hypotheses to encode a further propositional attitude. Since hypothetical thinking focuses on suppositions about possible worlds, type 2 processes have been attributed to hypothetical thinking, and this thinking is involved in type 1 and type 2 reasoning. From this point, it follows that reasoning is inherently argumentative (Mercier & Sperber, 2011) since hypothetical thinking functions to represent states of belief and knowledge of the world, not factual knowledge of the world. Moreover, hypothetical thinking inherently involves explicit reasoning and evaluation processes. Therefore, this study views the mental model not only as epistemic, but also as explicitly hypothetical or suppositional in nature (Evans, 2008, 2011).

Type 1 processes function to deliver the initial mental models to type 2 processes; however analytical thinking or type 2 reasoning may or may not appear. If the model cannot be satisfied, analytical/reflective thinking will revise or replace it, which may inhibit the initial heuristic (Evans, 2006). In this sense, the two processess occur independently and work complementarily, and are not simply sequential or parallel. Evans (2011) postulated three principles to explain these phenomena:

> First, the singularity principle states that only one hypothetical possibility (mental model) is considered at a time; second the relevance principle states the most relevant model will be considered first, cued by the context and by default the most probable state of affairs; finally, the satisfying principle states that the current model (hypothesis) will be retained unless there is good reason to give it up. (Evans, 2011, p.93)

Of importance here is that the satisfying principle requires evaluation. Mental models are evaluated with reference to the current goals and accepted if satisfactory (Evans, 2003). This evaluation takes place in type 2 processes, and requires the intervention of analytic/reflective processing such as explicit reasoning (see the intervention model proposed by Evans [2011, p.94]). According to Evans (2006), there are three factors that influence the likelihood of invention: a) cognitive ability, b) instruction, and c) time. The first factor is cognitive ability or working memory capacity. Analytic/reflective processing serves as the intervention. In this intervention, heuristic/intuitive processing always engages since analytic/reflective processing uses sources generated by heuristic/intuitive processing. In heuristic/intuitive processing, the implicit reasoning is utilized through fast and automatic processes to search for the most relevant information in the current context. Working memory, of course, serves as the fundamental vehicle for this search, but this kind of retrieval processing takes place in long term memory. Differing from heuristic/intuitive processing, analytic/reflective processing involves explicit reasoning such as analysis, manipulation, synthesis, and most importantly evaluation of the resources generated by heuristic/intuitive processing to search for the potentially most relevant information with reference to the current goals of being satisfactory. Hence, explicit reasoning as the core of the analyzing processing in analytic/reflective processing serves as the primary cognitive ability that emerges in working memory to generate the most believable arguments against other conditional beliefs. For example, in Kyllonen and Christal's (1990) research on relationships among working memory capacity, reasoning ability, and general intelligence scores, the authors reported results that demonstrated a consistently high correlation between general reasoning ability and general working-memory capacity. Therefore, cognitive ability plays a crucial role in both implicit and explicit reasoning, and vice versa.

The second factor is the use of instruction requiring abstract or logical reasoning. Importantly, reasoning is not a given, but rather only happens when an intervention emerges, such that people can engage in analytic/reflective processing. Building on this concept, Evans (2011) stated that the evolution of language with humans' meta-representational facilities is one of the key resources for reflective processing. Mercier and Sperber (2011) also argue that the emergence of reasoning is best understood within the framework of the evolution of human communication. From these points, language or communication-based instruction influences the likelihood of having an intervention that stimulates analytic/reflective processing. For example, Stanovich and West (1997) report that people with higher cognitive ability cannot just reason more accurately, but can also inhibit belief-based reasoning when instructed to reason logically.

The third factor is time. Time also influences the likelihood of an intervention that activates more analytic and reflective forms of thinking. Some studies show that when participants are required to respond quickly to reasoning problems, default heuristics dominate the responses (Evans, 2006). For example, several scholars report findings of participants producing matching bias (Roberts & Newton, 2001), belief bias (Evans & Curtis-Homes, 2005), and more frequent endorsement of fallacious inferences (Schroyens, Schaeken, & Handley, 2003) when they are allowed only a short time to respond.

In brief, the dual-processing model accounts for human cognition such as reasoning, judgment, decision-making, and social cognition. In terms of reasoning, type 1 reasoning as heuristic/intuitive processing is distinguished from type 2 reasoning including analytic/reflective processing. However, this does not mean that type 1 reasoning only involves simple inference and intuition without any cognitive processes. Rather, people still engage in multiple cognitive processes to construct most plausible or relevant claims based on task features, current goals, and their background knowledge. Type 2 reasoning is clearly linked to the development of cognitive ability, and combines and competes with multiple type 1 reasoning. In other words, hypothetical thinking that involves analytic and reflective thinking should embrace drawing inferences that are good enough or plausible in the context of current representations, but that are always subject to revision and rejection in the light of new evidence (Evans, 2006). That is, type 2 reasoning intervenes and competes with fast heuristic/intuitive processing. This intervention is influenced by three factors including cognitive ability, the use of instructions, and time. These factors play a crucial role in making this intervention available for more effortful and reflective forms of thinking. Therefore, since type 2 reasoning is what students need to learn and practice, we need to consider these three factors that influence the likelihood of intervention available for the analytic/reflective thinking that learning science requires.

Drawn from a dual-processing account of human cognition, Galbraith (2009) proposed dual-processing models of two systems of writing: the writing-retrieval system and writing-constituting system. However, it is worth noting that the two processes are both necessary for effectively developing writers' understanding. The knowledge-retrieval system works to explicitly organize the text and to ensure that this organization satisfies rhetorical goals. This system helps writers guide their explicit representation of what they have to say. In this sense, planning as a way to construct a clear mental model before writing is important for identifying potential aspects of the topic that need to be included in texts. The knowledge-constituting system, however, synthesizes knowledge activated by the knowledge-retrieval process into explicit, connected sentences. Differing from the knowledge-retrieval system, which aims to elaborate existing knowledge, this system includes two processes: a) synthesizing knowledge activated by the knowledge-retrieval system, and b) discovering relevant knowledge during text production. In other words, without the knowledge-retrieval system, it is difficult to think of creating new knowledge that satisfies rhetorical goals and captures the writer's implicit understanding of a topic. Therefore, the two systems simply cannot be seen as a cognitive conflict. Rather, both have complementary and sometimes competing relations. This new model proposed by Galbraith (2009) helps not only to expand our understanding of how writing can help to create new knowledge, but also overcomes the limitation of previous models that see thinking and language production separately. Table 1 summarizes the features of the two systems.

Table 2-1 Contrasting Characteristics of the Two Systems Involved in the Dual-Process Model[3]

Features of system	Knowledge-retrieval system	Knowledge-constituting system
Form of representation	Explicit representation of knowledge in separate fixed units	Implicit representation of knowledge in connections between units
Generation of content	Retrieval from memory	Synthesis
Organization of content	Associative spread of activation within long-term memory or goal-directed manipulation of content in working memory	Feedback from content in working memory to writer's disposition

Navigating Two Processes on the Continuum

Based on the dual processing accounts, figure 2-5 illustrates a schematic representation that exhibits the way type 1 processing interacts with type 2 processing. In this section, I utilize this schematic representation to introduce my perspectives regarding reasoning, language, and knowledge that emerges in students' written discourse, which is the primary goal of this study. This representation is rooted in four premises. First, type 1 processing is always involved in human cognitive processes. In multiple cognitive processes, type1 processing serves to generate resources that are used for type 2 processing. Type 1 processing, by contrast, never includes type 2 processing (Evans, 2011). The major function of type 1 processing is to retrieve the most relevant knowledge claim (mental model, or information), while that of the relative complement of type 1 processing is to evaluate what type 1 processing generates. Therefore, this schematic representation shows that every pathway that travels from O to outside the two systems traverses type 1 processing.

Second, type 2 processing is complementary to and competitive with type 1 processing. When type 2 processing is not fully crafted, it is type 1 processing that

[3] Source: Galbraith, 2009, p.22

people generally rely on in reasoning, decision-making, judgment, and other cognitive processes (Evans, 2006; Galbraith, 2009). Type 2 processing, therefore, is inherently complementary to type 1 processing. When the knowledge claim from type 2 processing emerges in one's cognitive processes, it should compete with the original inference or intuition retrieved by type 1 processing. The knowledge claim from type 1 processing has been considered the most plausible or relevant to solve the current problem in that situation. Although a person may be dissatisfied with the current knowledge generated by type 1 processing, if a new knowledge claim that attempts to revise or replace the original claim is not intelligible, plausible, or fails to provide more fruitful explanation or prediction, it is less able to revise or replace the original knowledge claim. This idea is associated with conceptual change literature (See Posner, Strike, Hewson, & Gertzog, 1982). In this sense, type 2 processing also inherently competes with type 1 processing.

Third, both systems occur independently. A highly motivated type 1 processing does not initiate the emergence of type 2 processing. Rather, it may serve to suppress type 2 processing. Thus, the size of each system is flexible, and depends on topics, available resources, and contexts. Those factors are also influenced by individual personal experience, knowledge, and cognitive ability. Therefore, some people have a relatively large proportion of type 1 processing, while others do not. However, it is important to note that the emergence of type 2 processing does not directly offset the original knowledge claim that is generated by type 1 processing.

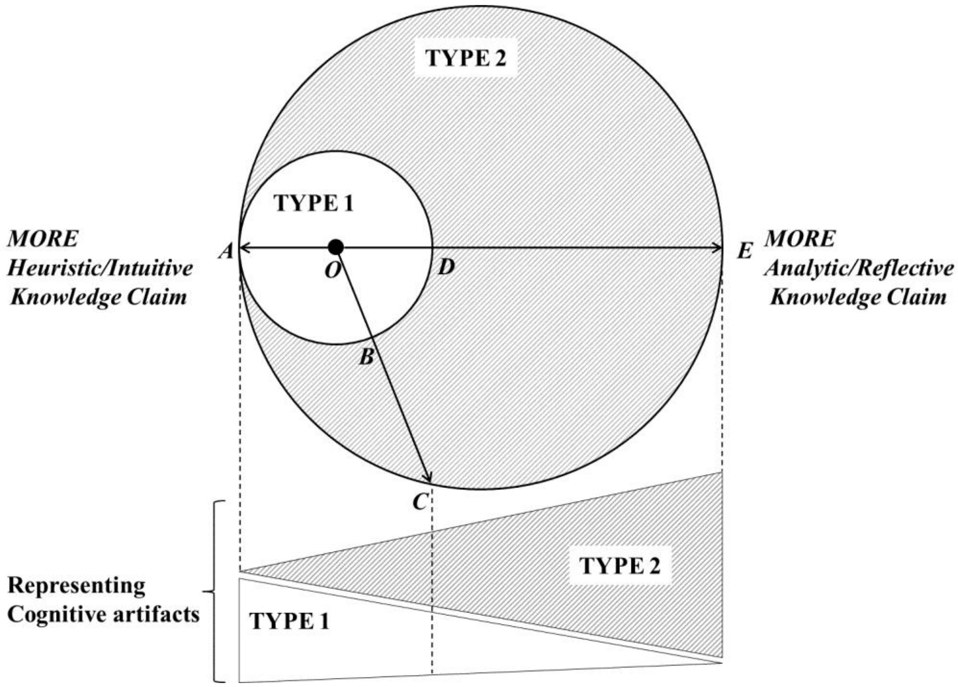

Figure 2-5 The continuum created by interaction between Type 1 and 2, proposed by the researcher

Four, representing cognitive artifacts are characterized as the interactive continuum between type1 and 2. Reasoning, language, and knowledge that emerge in students' written discourse are the cognitive artifacts with which this study deals, and those are represented by the outcomes of how people pass by pathways from O in type 1 processing to the outside of type 2 processing in figure 2-5. Figure 2-5 was proposed by Yoon and Hand (2012) to illustrate interactive continuum between type 1 processing and type 2 processing. In this figure, numerous pathways exist. Thus, it might be implausible to argue that people automatically move from type 1 processing to type 2 processing. Moreover, it is not necessary that the pathways follow the shortest distance between O to a point of boundary on type 2 processing.

However, this figure illustrates some examples of conditions under which people's cognitive processes travel the shortest distance. In this figure, two circles (systems 1 and 2) share a point of contact, and every pathway starts from a point, O. Since it is not necessary for type 2 processing to appear in cognitive processes, if the pathway passes through A (OA), the observable characteristics of representing cognitive artifacts are heuristic and intuitive reasoning, language, and knowledge claim. In a case of pathway of OBC, the process starts from O, passes by B and exits type 2 processing by passing by C. Since this pathway goes through both systems, representing cognitive artifacts illustrate both features. When moving toward the right end of the continuum, the area of type 1 processing is decreasing while that of type 2 processing is increasing. The emergence of type 2 processing means that analytic and reflective processing occurs. In other words, the original reasoning, language, and knowledge claim generated by type 1 processing can be revised and modified while staying in type 2 processing since the primary function of type 2 processing is evaluation. In an extreme case when arriving at point (E), the original cognitive artifact can be entirely replaced by the new one generated by type 2 processing, so that it is only type 2 processing that appears in the representing cognitive artifact.

Although most descriptions above do not specify a dual-processing model of writing, the four premises suggested above can apply to the dual-processing model of writing. In brief, the knowledge-retrieval process is always included in the knowledge-constitution process. To construct a new knowledge claim, writers need both internal/implicit resources generated by the knowledge-retrieval process, and external/explicit resources including previously produced texts, the writing task or topic, and so forth. They evaluate multiple resources to generate the most plausible and relevant claim, as well as to satisfy the intervention of evaluating processes that emerges during the knowledge-constitution process.

During the course of these processes, the original claim retrieved from type 1 processing (the knowledge-retrieval process) interacts with the new claim generated by type 2 processing while also evaluating multiple potential claims and resources used for developing the claims. Finally, writers can synthesize multiple sources and claims to produce a new knowledge claim as opposed to retrieving an old claim. However, the new claim does not always occur. If writing tasks require writers only to retrieve their stored knowledge and to articulate language that serves as a representing tool, it is less likely that the writers will engage in the knowledge-constitution process. The likelihood of the emergence of the knowledge-constitution process also depends on writers' cognitive capacity, which plays a critical role in interactions between dispositional and linguistic knowledge. Based on the dual-processing account, there are also other factors, including: a) instruction, enabling writers to be exposed to the environment in which they can experience and practice cognitive processes, especially evaluation processing, and b) time, enabling them to have enough opportunity to reflect in and on ideas they retrieved and have newly generated. In this sense, it is argued that writing helps writers' cognitive development.

However, in the dual-processing accounts that we use as the fundamental theoretical frameworks for this study, cognitive development is not the primary topic that researchers aim to explore. Furthermore, it is unreasonable to argue that replacing type 1 processing with type 2 processing can be understood as developmental progress.

According to authors who study dual-processing, although there is a growing number of studies that attempts to explore this issue (See a special issue in *Developmental Review* [2011, vol. 31]), the derivation of predictions for cognitive development is far from straightforward (Evans, 2011). Moreover, the developmental approach has rarely been used to refine or test these dual-processing accounts (Stanovich, West, & Toplak, 2011). Therefore, it may be challenging to directly use this dual-processing account in exploring students' cognitive development, which is the aim of this study. However, it is worth noting that most of the studies in dual-processing theories emphasize long-term and successive cognitive development from child to adolescent to adult. It may be impossible to track people's cognitive development over the course of an entire lifetime. Therefore, it is necessary to narrow our scope of cognitive development from the development during a lifetime to the development that students experience in the course of learning in a particular educational setting.

Experience Shifts and Practice Navigating those Shifts

Klein (2006) has greatly contributed to addressing the development of students' understanding through the use of language. Although he does not mention any dual-processing accounts, he opens new spaces, helping us to think about how students can develop their cognition related to reasoning, the use of language, and knowledge. Drawn from cognitive psychology, he insightfully provides theoretical suggestions that help us to re-conceptualize cognitive development in educational settings. When students learn science, they engage in diverse learning opportunities that involve cognitive processes and social interaction. These opportunities may vary, but involve developmental moments in which students experience multiple shifts in terms of cognitive development that includes reasoning, the use of language, and knowledge construction. This cognitive development through engaging in multiple cognitive processes can be linked to dual-processing accounts. Before discussing this link, we first look into Klein's (2006) account of cognitive development.

Klein (2006) classified cognitive accounts as first generation and second generation in terms of reasoning, the use of language, and knowledge construction. From the first generation perspective, reasoning or thinking is a process of physical symbol manipulation, and is explained in terms of meaning-neutral formal rules, such as deductive logic, for manipulating propositions. Knowledge is constructed as a system of propositions, comprised of strings of classical concepts with necessary and sufficient features and well-bounded sets of referents. Language is viewed as a by-product of thought. From a first generation cognitive psychology perspective, cognition operates on representations similar to those of science knowledge that scientific text represents. Meanwhile, second generation cognitive psychology perspectives explain that concepts are perceptually based, fuzzy, and contextual. With respect to reasoning or thinking, the mind is modeled as a connectionist network engaged in perceptual simulation or pattern completion and analogy. Language is primarily metaphorical and narrative.

Klein (2006) does not explicitly explain cognitive development as shifts that emerge when two different generations of cognition interact with one another. However, the shifts are introduced as what students need to go through in order to improve both fundamental and derived senses of scientific literacy (Norris & Philips, 2003). Therefore, it can be argued that the shifts are closely associated with the cognitive development that this study aims to explore. Klein (2006) focused on three shifts in terms of reasoning, the use of language, and knowledge construction. He argued that there is: a) a shift that emerges while students develop formal reasoning, which requires understanding scientific concepts based upon their perceptually driven reasoning, b) a shift that emerges while students develop written arguments as a form of scientific texts based upon the oral-based language that they use daily, and c) a shift that emerges while students develop the classical concepts that are understood as a form of scientific concept based upon their fuzzy and contextual concepts of the world. Although Klein (2006) highlighted the second generation of cognition, he was not arguing that there is a right or wrong between the two different generation theories when adopting them in science classrooms. Instead, he argues that there is a difference between the two approaches, and that each is beneficial to the learning and teaching of science. He continues to argue that science literacy education needs to mediate between the relatively denotative nature of science texts and the expressive nature of everyday thought and language.

How can these shifts be linked to dual-processing accounts? In dual-processing accounts of reasoning, the role of type 1 processing is to construct a default inference regarding a topic based upon background knowledge and the contextual understanding that students already possess. This heuristic or intuitive processing is linked to implicit reasoning since cognitive processes engage in retrieving the most plausible or relevant knowledge claim. This relatively quick process is thus influenced by contexts. Students' perception, prior knowledge, and experience also play a key role in the construction of the default inference, which can be seen as the outcome of this process. In this sense, the inference that students initially generate is not always scientifically acceptable. Rather, it shows students' perceptually driven reasoning, and fuzzy and contextual understanding of a topic. However, this does not mean that they do not have any cognitive capacity to produce scientifically reasonable knowledge claims at that moment since students may be able to construct scientific accounts depending upon the topic. In terms of language use, students are more likely to use contextualized language that is frequently used while engaging in a particular event, activity or episode. Or they may use their own language since the default inference is generated from perceptions, beliefs, knowledge, and experiences that they previously accrued or currently maintain. In this regard, type 1 processing is linked to the second-generation cognitive psychologists' perspectives. Students' multimodal representations will show similar patterns to their use of language.

Multimodal representations may be simpler, but contextualized, forms, so that it may be difficult for others who are not engaged in the same context to entirely interpret and understand them. This is because students focus more on generating their ideas without concerning potential readers or audiences. In this sense, a lack of coherence will appear.

Meanwhile, the most distinctive feature of type 2 processing is the evaluating process. This involves the intervention that analytic or reflective processing effects. Influenced by these factors, the emergence of the intervention may evoke the shifts that Klein (2006) suggested. However, all intervention does not automatically result in constituting scientifically reasonable knowledge claims since there are multiple factors that can create bias. Moreover, since scientific knowledge and texts are socially generated via critical reviewing processes in the scientific community, the degree of cognitive actions is much beyond an individual cognitive process. However, distinctive features of the first generation of cognitive psychology may be observed near the right side of the continuum in figure 2-5. Importantly, these features can be observed when they are in a particular environment where the intervention frequently occurs by encouraging students to improve their cognitive capacity, providing instructions that require them to engage in analytic and reflective processes, and offering enough time and space so that students have opportunities to review and reflect on their ideas. Under this condition, representing students' cognitive artifacts will be located near the right end of the continuum in figure 2-5 where formal reasoning occurs. Students, therefore, will use explicit reasoning more frequently, which can be observed in written arguments, and the use of the explicit reasoning will help to construct and critique their scientifically reasonable knowledge claims. In this sense, representing knowledge claims tend to have a more denotative nature, so that students' use of language is not necessarily linked to any specific context. This fact may influence their multimodal representation. The representation becomes more complex since students may include more representative devices, such as labels, for informative purposes. Despite the complexity of representation, coherence will be increased since they may start to consider their readers or audiences who are not in the same context, thereby potentially attempting to inform clearly and to create distance between self and representation.

Summary of Chapter

In this chapter, the researcher has presented existing literature that explains and supports practices of scientific literacy, science argumentation, and writing, and has also explained the theoretical framework that grounds this study. Table 2-2 summarizes the assumptions of previous literature upon which this study was based. Since this study explored students' use of language, it approached language both in terms of its use as an epistemic and a representational tool, and proposed a new concept of Discourse Space to deepen an understanding of students' use of language for learning. With this understanding, this study explored three shifts that could be observed in students' use of language, knowledge construction, and thinking suggested by Klein, and in this exploration, dual-processing theory worked as the theoretical foundation to guide this study.

Table 2-2 The Researcher's Assumptions about Scientific Literacy, Argumentation, and Writing for this Study

I believe that:	However, there is a need to consider that	Therefore, this study aims to
… there exists a symbiosis between the two senses of science literacy (Gee, 2005).	…it was a sincere belief that achievement of the fundamental sense of science literacy will lead to achievement of the derived sense of science literacy. This symbiosis still lacks evidence (Yore & Treagust, 2006).	…investigate this symbiosis by exploring students' use of language (the fundamental sense of scientific literacy) to understand the development of their understanding (the derived sense of scientific literacy).
…argumentation is understood as a core practice to achieve scientific literacy (National Research Council, 1996; Osborne, MacPherson, Patterson, & Szu, 2012; Cavagnetto, 2010).	…only the immersion oriented argumentation approach appears to fully capture the culture, including the epistemic nature of science that is embedded in scientific practice (Cavagnetto, 2010).	…explore a classroom implementing the SWH approach as one possible approach to help students achieve both a fundamental *and* a derived sense of scientific literacy by providing a learning environment in which students are immersed in argumentation.
…the goal of argument instruction in the context of scientific literacy is the transfer of an understanding of scientific practice, rather than the transfer of an understanding of the structure of argument (Cavagnetto, 2010; Ford, 2008a).	…a) to grasp scientific practice, students need to learn not only how to play the role of constructor, but also how to play the role of critiquer in the community (Ford, 2008a). …b) writing plays a crucial role not only in argumentative practice (Hand, Gunel, & Ulu, 2009; Keys, 1999; Sandoval & Millwood, 2005; Wallace, 2006), but also in the grasp of scientific practice (Chen, 2011; Benus, 2011).	…explore the development of students' understanding through writing as argumentative and scientific practice when students are immersed in argument-based inquiry such as the SWH approach, in order to empower them to become literate in the Discourse of Science.

CHAPTER THREE

METHODS

My View of the World

> In general, skepticism takes the form of a request for the justification of…knowledge claims, together with a statement of the reason motivating that request. (Grayling, 2003, p.45)

In this section, I will briefly introduce my view of the world. My epistemological view of the world is interactive constructivism. According to interactive constructivists (Henrique, 1997), knowledge is constructed by the interaction between private negotiating processes (radical constructivism) and public negotiating processes (social constructivism). Radical constructivism is an epistemological model for examining cognition in an individual as he or she makes meaning of experiences, while social constructivism is an epistemological model for using language to study the making of meaning in groups (Staver, 2012). The implementation of interactive-constructivists' perspectives into teaching and learning often utilizes an ecology metaphor to illustrate learning in which dynamic interactions of prior knowledge, concurrent sensory experiences, belief systems, and other people in a sociocultural context lead to multiple interpretations that are verified against evidence and privately integrated into a person's knowledge network (Yore, Anderson, & Shymansky, 2005, p.67). In this light, knowledge can be understood as individualistic conceptions of reality (radical constructivism) that have been verified by the epistemic traditions of a community of learners (social constructivism). Therefore, my view of the way people understand and explain how we know what we know is that knowledge claims can be constructed by the constant interaction between these two different epistemological models.

Maintaining multiple interpretations of the ontological world is not problematic; I believe that multiple interpretations can work as crucial resources to build a potential reality that has been verified by the epistemic traditions of a community. As such, my ontological view of the world is not relativism, even though it has been argued that the ontology of constructivism is relativism (Guba & Lincoln, 1994). According to the authors, all realities exist in the form of multiple, intangible mental constructions, which depend on the individual persons or groups holding the constructions (Guba & Lincoln, 1994). This view may be supported by the epistemological idea that knowledge is actively built up from within by each member of a community and by a community itself (Staver, 1998). However, the constructed knowledge claim cannot be understood as a truth or a representation of reality. Rather, the constructions that individual persons or groups hold should be understood as pieces of a puzzle. People engage in dynamic interactions of prior knowledge, concurrent sensory experiences, belief systems, and other people in a sociocultural context. These dynamic interactions constitute networks that serve as interlocking pieces of a puzzle, which can then be seen as a bigger and more plausible representation of reality. Therefore, my ontological view of the world is realism.

Although Crotty (1998) argued that constructivism and realism are compatible, there are several critical points of collision between the two. Staver (2012) introduced constructivism and realism as dueling paradigms by suggesting that "constructivists and realists remain deeply divided over the question: Can we justify that anything we know represents some aspect of reality?" (p.1022). The answer may not be a simple 'yes'. However, I believe that one of the fundamental reasons people keep engaging in scientific practice is to develop more plausible claims and evidence to 'justify that anything we know represents some aspect of reality.' In this context, Staver (2012) argued that knowledge constructed through research is considered stronger when it is supported via multiple, independent lines of evidence. This can be paralleled to the metaphor of constructing a puzzle. In the process of interlocking the pieces, people are able to gain a better understanding of what the puzzle's big picture looks like. Critical to this process are not only the activities of constructing knowledge claims and creating evidence to support them, but also evaluating previous claims and evidence to advance that knowledge.

From these points, it seems that skepticism may play a crucial role in building a bigger and more plausible representation of reality. Intuitively, the word skepticism may evoke negative connotations; however, skepticism in science not only makes doing and engaging in scientific practice healthier, but can also work as a bridge to resolve the conflict between my epistemological and my ontological views of the world. Even further, skepticism can lead to "seeing complication and multiple realities" (Stake, 2010, p.54). In this regard, my emphasis on skepticism necessarily influences this study. In this research context, it can be linked to my belief that there is a need to emphasize evaluating processes as the core of type 1 processing, enabling students to travel between their fuzzy human cognitive architecture and valid scientific reasoning. Furthermore, skepticism can serve as a mediator between the constructivism that dominates in education and the realism that science itself has historically embraced.

Research Design

This study was guided by the research question: What are the patterns of the development of fifth grade students' cognition over time that emerged in their private and public negotiations under a teacher who is ranked as a low-level implementer of the SWH approach? This question was divided into two sub-questions: (a) throughout a unit, Ecosystem, what patterns emerge regarding the development of six fifth grade students' understanding through writing, and b) what are the patterns of the development of discourse space through talking in three different contexts. In order to answer these questions, this qualitative research employed a generic qualitative study (Merriam, 1998).

Since qualitative research explores the ways that individuals construct reality in interaction with their social worlds, constructivism underlies the generic qualitative study. I was therefore interested in understanding the meaning a phenomenon has involved (Merriam, 2009, p.22). Since meaning "is not discovered but constructed" (Crotty, 1998), this generic qualitative study was interested in three foci: "a) how people interpret their experiences, b) how they construct worlds, and c) what meaning they attribute to their experiences" (Merriam, 2009). In this regard, generic qualitative research could help to explore a) students' learning experiences, b) meanings generated by students through discursive practice, and c) the relationship between their experiences and the generated meanings.

Context

School

The study was conducted in a fifth grade science classroom taught by one white female teacher at a rural elementary school in the Midwestern United States. This school taught grades kindergarten through five. During the 2011-2012 academic year, the school district served 100 students with approximately 45.5% of students qualifying for free and reduced lunch (6.4% of students qualifying by income, 32.3 % by direct certification, and 6.8% by reduced lunch) and 7.3% of students identifying as eligible for Individual Education Programs (IEP). The ethnic diversity of the student population at the school was 95.0% White, 4.1% Hispanic American, 0.5% African American, and 0.5% Native American.

Mrs. Shelly and her Instruction

The participants' teacher, Mrs. Shelly (pseudonym), has 25 years of experience teaching fifth grade science. Mrs. Shelly utilized an argument-based inquiry approach for teaching and learning science, namely the SWH approach. One year prior to the study, Mrs. Shelly participated in SWH professional development workshops and since has adopted the SWH approach as the primary pedagogical approach in her classroom.

As part of previous work on the SWH research project, participating teachers videotaped their implementation of the SWH approach during the 2010-2011 academic year. Those videos were collected and scored separately by research team members using the modified Reformed Teaching Observation Protocol (RTOP) (Sawada, Piburn, Judson, Turley, Falconer, Benford, & Bloom, 2002). The original version of RTOP was designed as an observational instrument that could be used to assess the degree to which mathematics or science instruction is reformed based upon the recommendations and standards for the teaching of mathematics and science. The revised protocol focused more on a learning context in which students were immersed in the argument-based inquiry approach in their science classes. In this sense, the research team modified and used four major categories: a) students' voices, b) teacher's voice, c) problem solving and reasoning, and d) questioning. Appendix A shows the general features of three groups based on the four categories. The protocol utilizes a Likert-type scale with a range from zero to four.

Mrs. Shelly's implementation videos from the previous year were also collected and scored by the research team. In terms of interrator reliability, which refers to "the extent to which the different judges tend to assign exactly the same rating to each object" (Tinsley & Weiss, 2000, p.98), the research team utilized the Cronbach's Alpha based on standardized items to estimate interrator reliability (0.924; $p < .01$) in scoring the teacher's classroom observation ($n=16$). Based on RTOP scores, researchers divided participating teachers into three groups: high, medium, and low. All of Mrs. Shelly's teaching videos indicated that she was in the low group based on RTOP score. Therefore, it could be argued that in the previous year, Mrs. Shelly's science classes missed some aspects of the SWH approach. The SWH approach asked teachers to provide students with opportunities to learn about the nature, structure, and process of scientific argument. In this approach, students were immersed in the discourse and practices of inquiry and critical debate by setting their own investigative agenda for laboratory work, framing questions, proposing methods to address these questions, and carrying out appropriate investigations. As such, classroom dialogue and the negotiation of ideas could be understood as an essential part of learning science. All students were encouraged to engage in scientific discourse and activities so as to explain, share, and develop their ideas and understanding of the lesson topic. In addition to the dialogical interactions, writing was used as a critical component to learning in science classes. During each instructional period, time was devoted for students to write ideas based on their observations, readings, and reflections. Additionally, students were encouraged to take notes throughout the class.

Students' idea about Ecosystems

The topic of the first unit, this study explored, was Ecosystems in biology. The big idea that Mrs. Shelly presented to her students was "Living things interact with and depend upon one another and their environment." To have a better understanding of this unit, I reviewed curriculums and research on students' ideas of ecosystem. This understanding guided me when examining the development of students' cognition regarding ecosystem.

There have been a variety of curriculums suggested in science education. However, the NSES was seen as the most largely and broadly acceptable and reliable resource for teachers and researchers to understand what essential concepts and/or skills that students were expected to learn throughout this unit. In addition to NSES, since the study was conducted in Iowa, and Mrs. Shelly was highly recommended by school principle to implement the Iowa Core Curriculum (ICC) in her class, I also reviewed the ICC. For this unit, the authors of NSES (NRC, 1996) stated that:

> Students should progress from studying life science from the point of view of individual organisms to recognizing patterns in ecosystems… Students should broaden their understanding from the way one species lives in its environment to populations and communities of species and the ways they interact with each other and with their environment. (p.155) …Students understand ecosystems and the interactions between organisms and environments well enough by this stage to introduce ideas about nutrition and energy flow, although some students might be confused by charts and flow diagrams. If asked about common ecological concepts, such as community and competition between organisms, teachers are likely to hear responses based on everyday experiences rather than scientific explanations. Teachers should use the students' understanding as a basis to develop the scientific understanding. Understanding adaptation can be particularly troublesome at this level. Many students think adaptation means that individuals change in major ways in response to environmental changes (that is, if the environment changes, individual organisms deliberately adapt). (p.156)

According to an ICC document, students were asked to understand and apply knowledge of organisms and their environments, including: a) structures, characteristics, and adaptations of organisms that allow them to function and survive within their habitats, b) how individual organisms are influenced by internal and external factors, and c) the relationships among living and non-living factors in terrestrial and aquatic ecosystems. Based upon these two major sets of guidelines, for this unit Mrs. Shelly provided several activities including the general phases of the SWH approach.

What and how do students actually understand ecosystem? There are several attempts to explore students' ideas of ecosystem (see the Leeds National Curriculum Science Support Project). According to researchers (i.e. Leach, Driver, Scott, & Wood-Robinson, 1995; 1996a; 1996b) who participated in the project, there were students' common ideas of ecosystem as follows:

- Believe that plants take their food from the soil.
- Do not understand the significance of the sun as the source of energy.

- Think that soil, water and foods are factors required for animal growth; they do not consider these factors as sources of matter.
- Tend to think of food chains as linear. They have difficulty grasping the interdependence of organisms.
- Do not grasp the significance of green plants in a food web; they also believe that green plants exist solely for other organisms to eat.
- Think that predators can feed on all organisms at lower tropic levels.
- Are unaware of the role of microorganisms as decomposers and recyclers of nutrients within a food web.
- Many students conceptualize decomposition as the total or partial disappearance of matter.
- Have poor understanding of conservation of matter.

Mrs. Shelly's instruction did not include all concepts and information curriculum and researcher suggested, however this information helped to further explore the development of students' understanding. In addition to students' common misunderstanding of ecosystem, I examined concept maps presented by Science Literacy Maps, which National Science Digital Literacy distributed, to understand how concepts in ecosystem could be interconnected and synthesized (Appendix B). Concept maps were greatly helpful to investigate the development of cognition since the visualized connections between multiple concepts presented by the concept map were easily compared with concepts that students utilized in their texts for their cognition development. In this study, while analyzing data and describing findings, I used both information of students' ideas of ecosystem to grasp a better understanding of students' development of cognition. Table 3-1 shows classroom activities that students engaged in during the Ecosystems unit.

Table 3-1 Classroom Activities in the Unit on Ecosystems

Week	Day				
	Day 1	Day 2	Day 3	Day 4	Day 5
Week 1		Beginning Idea// Concept Mapping	Concept Mapping// Teacher Reading (*Giving Tree*)	Concept Mapping// Inquiry Question	No Science Class
Week 2	No Science Class	Inquiry Question	Inquiry Question	Group Work // Inquiry Question	Group Work // Inquiry Question
Week 3	No Science Class	Group Work // Inquiry Question	Teacher Reading (*Biodiversity*)	Design Test	Design Test
Week 4	Group Work	Group Work // Microscope	Group Work	No Science Class	No Science Class
Week 5	Group Work // Microscope	Group Work // Comparing Ideas with Experts	Group Work // Comparing Ideas with Experts	Group Work // Teacher Eeading (*Ecosystems*)	Group Work // Cross Puzzle// Watching Video (*Garbage*)
Week 6	Group Work	Group Work // Teacher Reading (*Pollution, Global Warming*)	Group Work // Watching Video (*Global Warming*)	No Science Class	Group Work // Teacher Reading (*Saving Energy*)
Week 7	No Science Class	Group Work // Watching Video (*Pollution*)	Group Work // Teacher Reading (*Pollution*)	Presentation// Teacher Reading (*Pollution*)	No Science Class
Week 8	Presentation// Watching Video (*Wetlands*)	Presentation// Wetlands	Presentation	Class Discussion (*Variables*)	Class Discussion (*Changes in Ecosystems*)
Week 9	Summary Writing	UNIT 2			

Participants

Twenty-one fifth grade students participated in this study from Fall 2011 to Spring 2012. Since Fall 2010, the participating teacher had used the SWH approach as an instrument for promoting science inquiry at elementary levels. Participating fifth grade students in Mrs. Shelly's class therefore had one academic year's experience with the SWH approach when they were fourth graders, during which there was a strong emphasis on the use of language while immersed in an argument-based inquiry approach in the science classroom. As fifth graders, the students attended approximately five fifty-minute science classes per week.

Mrs. Shelly taught two different classes of students, but I selected her home students as the participating class for two reasons. First, Mrs. Shelly had a better understanding of these students in terms of their background, reading ability, achievements in other disciplines, and performance beyond the science classroom. Although this study did not aim to examine the elements listed above, exploring the teacher's homeroom class was more beneficial because a teacher's understandings of her students, as one of the core elements of a teachers' knowledge (Park & Oliver, 2008), influenced the interaction between the teacher and the students, as well as the development of the students' understanding.

Furthermore, Mrs. Shelly's homeroom students were more likely to feel familiar and comfortable with interacting with Mrs. Shelly than with another teacher. This physical and psychological familiarity might have helped to create a non-threatening learning environment, which was understood as a core condition for the emergence of negotiation for learning (Yoon, Bennett, Mendez, & Hand, 2010). Since this study explored the Discourse Space that participating students and Mrs. Shelly created in their science classes, I therefore selected Mrs. Shelly's homeroom students as the participating class.

Among twenty-one students, six were purposefully selected through which to further investigate the development of an understanding of science through private negotiation while immersed in a language-based argument inquiry approach. Patton (1999) suggested that "the logic and power of purposeful sampling lies in selecting *information-rich* cases for study in depth. Information-rich cases are those from which one can learn a great deal about issues of central importance to the purpose of the research, thus the term *purposeful* sampling" (p.169). The fundamental premise behind selecting six participants was to allow for: (1) a depth of data collection for each student as a case study (number of participants needed to be small enough), (2) a representative case study of each group (multiple students may better represent the characteristics of each group), and (3) a common thread among participants (multiple students in different groups may better portray general patterns or regularities within classrooms).

To purposefully select six target students for this study, performance on the Cornell Critical Thinking test (CCT), the students' first writing sample analysis and level of verbal participation in public negotiation, and the group members assigned by Mrs. Shelly were considered. First, the CCT was used to sort students, as students completed the CCT test at the beginning of the semester. The CCT is designed to examine students' critical thinking skills, and includes students' understanding of induction, deduction, credibility, and identification of assumptions. According to dual process theory students' cognitive ability is understood as a critical element of the likelihood of the emergence of the intervention that type 2 processes such as analytic or reflective processes effect (Evans, 2006). With this in mind, the researcher purposefully categorized students into three groups to explore the similarities and differences between groups. Therefore, depending on students' critical thinking test scores, they were categorized into three groups - high, medium, and low. According to normal distribution, there were only two students in the high and low groups. Because of this, other steps were used to select the two participants in the middle group.

Next, an examination of the students' use of language was used for selecting the two students in the middle group. This examination was based on the first writing sample analysis (writing) and level of verbal participation (talking) For the students' first writing sample analysis, I adopted an analytical frame that I as a member of a research team developed to measure students' writing skills (Yoon, Bennett, Mendez, & Hand, 2010). Students' writing skills at the very beginning of the academic year were examined in terms of fluency (vocabulary, conventions, and sentence fluency) and coherency (effective organization). Each category was scored with a 0 to 3 scale, so that the total score of this analysis was twelve (Appendix C). Three graduate students who participated in the development of this analytical matrix analyzed the students' first writing samples independently and then compared scores to calculate the interrator reliability. The final result of calculating the interrator reliability was .90.

The level of verbal participation was also examined. I calculated the frequency of utterance that had occurred during the first week (three science classes) for each student. During the first week, students engaged in initial activities to practice argumentation in the science classroom before learning the big ideas of science. These activities included identifying a candy bar based on observation of pictures illustrating the crosscutting phase of candy bars. In this activity, students were encouraged to practice creating claims and evidence, and engaged in whole class discussion and small group activities. The utterances that occurred in the whole class discussion were counted. The total number of utterances was 273.

As a result of examining the students' use of language, two students in the middle group were selected for further study. Since there was no significant difference between the students' first writing sample analysis across the groups, the level of verbal participation was largely used to select two participants in the middle group. Interestingly, the two students in the high group were identified as talkative, while the two students in the low group were identified as non-talkative. Therefore, for two students in the middle group, I selected one talkative student and one non-talkative student out of the students who had similar scores in the first writing sample analysis.

To finalize participant selection, group members were considered. Students were divided into six groups in the second week of class for group investigation. Then, students in each group worked together throughout the Ecosystem unit to pose questions, design their tests, collect data, create claims and evidence, search for information that could support their evidence, and conduct their presentations. Since this study explored the development of Discourse Space when students engaged in private and public negotiation, I attempted to select at least one student from each group as a participant in this study. However, students in a particular group were not selected because of the CCT scores, the first writing sample analysis and level of verbal participation in public negotiation. As a result, I finally selected six students from five groups.

In summary, I divided students into three group based on CTT scores. Since there were only two students in the high and low groups based on these scores, I utilized two more steps to select participants in the middle group. The results of the students' first writing analysis indicated that participants in the high and low groups had similar scores. However, the results of the level of verbal participation indicated that the two students in the high group were talkative, while the two students in the low group were non-talkative. With this in mind, I intentionally selected one talkative student and one non-talkative student from the middle group who had similar scores on the first writing analysis and and who belonged to as widely diverse classroom groups as possible. Following are brief descriptions of the six participants; for confidentiality, all were given pseudonyms.

Michael: "Everything was, is, or will be science." Michael was a Caucasian male student. This quotation was his perspective of science as written down in his notebook (Notebook in August 25 [NB 0825]). He was the highest-scoring student on the CTT test. He actively engaged in group and class activities. In hands-on activities, he seemed to lead his group's discourse by raising ideas and questions for group tasks. In public negotiation, he always raised his hand to share his ideas, and Mrs. Shelly frequently used his utterance in whole class discussion.

Noah: "Science is all about questions" (NB 0825). Noah was a Caucasian male student. He was in the high group in terms of CTT scores. Similar to Michael, he tended to lead his group members in doing group work, and actively engaged in class discussion. He completed his tasks relatively faster than other group members, and then shared his ideas with them. For example, in a writing task, he completed his writing quickly and showed it to other group members, and then the other members copied what Noah had written down.

Chloe: "Science helps not just scientists, but kids learn that any question just needs some tests and data for a wonderful real answer" (NB 0825). Chloe was a Caucasian female student. She was in the middle group in terms of CTT scores. She was a very talkative student and was likely to dominate class discussions. She always spoke her ideas in a loud voice, and sometimes interrupted others' talking by breaking a rule which Mrs. Shelly had emphasized in class discussion about only one student talking at a time. She very actively engaged in public negotiation (talking), as well as private negotiation (writing). She carefully wrote ideas, but sometimes did not want to share her ideas with her group members.

Megan: "Science is when you study world or to see what plant would grow faster" (NB 0825). Megan was a Caucasian female student. She was in the middle group in terms of CTT scores. She was a non-talkative student. Although she appeared to actively engage in small group activities, actually she made only a small contribution to group work. In whole class discussions, she usually did not raise her hand, and only sometimes raised her hand and shared her ideas when the topic was related to her personal life.

Ruby: "Science is when you leon (learn) about stuff like when you learn about butterfly or how many bones you have and studie (study) them" (NB 0825). Ruby was a

Caucasian female student. She was in the low group in terms of CTT scores and was a non-talkative student. She did not frequently engage in whole class discussion; however, she worked hard in small group activities. In writing tasks, she spent more time on writing than her peers. When other students had already completed their work and started to make noise, she usually kept writing down her ideas. She was in some ways a very calm student.

Ivy: "Science is like tests" (NB 0825). Ivy was an African-American female student. She was in the low group in terms of CTT scores and the only African-American student in the entire school (kindergarten through fifth grade). She was a non-talkative student. She always showed her smile, but was very shy. She usually did not engage in whole class discussion, and tended to agree with others' ideas and opinions when engaged in small group activities. When Mrs. Shelly asked Ivy to share her ideas, she usually responded in a quiet tone, and sometimes muttered something to herself.

Table 3-2 Information about Participants in this Study

Student Name	CTT scores	Group Number	Level of Verbal Participation	First Writing Sample Analysis Score
Michael	High	Group 6	Talkative	7
Noah	High	Group 1	Talkative	6
Chloe	Middle	Group 2	Talkative	7
Megan	Middle	Group 5	Non-talkative	7
Ruby	Low	Group 2	Non-talkative	8
Ivy	Low	Group 3	Non-talkative	6

Note. Total score of the first writing sample analysis is 12.

Data Collection

Many qualitative data are composed of personal happenings in a specific time and place (Stake, 2010). However, there is not a single source that can present and represent "personal happenings in a specific time and place" best. To obtain a comprehensive perspective, the triangulation of sources, identified by Denzin (1978) and Patton (1999), is needed. Merriam (2009) stated that qualitative data collection, therefore, is about asking, watching, and reviewing (p.86). In this sense, this study collected a variety of sources of data and triangulated multiple data sources across different sources "at other times, in other spaces, or as persons interact differently" (Stake, 1995, p.112). The data for this study included both primary and secondary sources. The primary sources included students' writing samples, classroom observations, the researcher's field notes, and informal conversations with participants, and the secondary sources included the teacher's modified RTOP scores, a semi-structured interview with the teacher, and students' pre and post critical thinking test scores. In the following section, I describe the primary data first, and the secondary data next. Table 3-3 summarizes information regarding the data collected for this study.

Table 3-3 Summary of Type of Data and its Use

Type of Data	Description	Use	
Primary data			
Student writing samples	28 informal writing samples per student 2 formal writing samples per student	*RQ-1**	
Informal conversation	27 recorded informal conversations with teachers and students	*RQ-1*	*RQ-2*
Field notes	32 field notes	*RQ-1*	*RQ-2*
Video tapes	25 videos (all transcribed)	*RQ-1*	*RQ-2*

Secondary data			
Semi-structured interview	One-time semi-structured interview	*RQ-1*	*RQ-2*
Teacher's modified RTOP scores	28 lesson scores		*RQ-2*
Students' pre- and post-CCT test scores	21 students' test scores		*RQ-2*

Note. RQ-1/2 means that the data was used to answer the first/second sub-research question of the study. In this study, there were two sub-research questions.

This study collected three types of primary data. First, all kinds of written products (i.e. student-driven informal writing and teacher-driven formal writing by students in the science classroom) were collected. Second, field notes based on observations including informal conversations with participants were collected. Third, the researcher videotaped Mrs. Shelly's science classes and all videos were transcribed.

Students' Writing Samples

Writing is an important discursive tool for organizing and consolidating rudimentary ideas into knowledge that is more coherent and well-structured (Rivard & Straw, 2000, p.586). To explore the development of students' understanding through their engagement in discursive practice, it was therefore critical to examine written products. Six fifth grade students' writing samples were collected throughout the first unit, Ecosystem. Since Mrs. Shelly intentionally encouraged students to write in her science classes, they engaged in writing activities 36 times over the 9 week period covering the unit. On average, the students produced 36 pages of writing, but the length of this writing varied from a sentence to a page consisting of several paragraphs. This study divided students' writing samples into informal writing in their notebooks and formal writing that was required to be submitted to the teacher for assessment purposes. In the informal assignments, students did not have a specific audience for their writing.

In other words, it was themselves that students normally considered as their readers as they recorded their ideas, observations, questions, and reflections in their notebooks. The second type of writing was the teacher-driven formal writing, which was commonly used for assessment purposes. In this study, students' summary writing was used as the example of formal writing. In this writing activity, students were asked to write a letter to explain what they had learned throughout the unit.

Researcher's Field Notes

All researchers should keep at least one journal, and even better two or more (Silverman, 2000, p.191). Field notes are the fundamental database for constructing case studies and carrying out thematic cross-case analysis in qualitative research (Patton, 2001). In this study, the researcher recorded field notes based on non-participant observation and informal conversation. Using an observation sheet, I recorded field notes during and immediately after each classroom observation. On the sheet, four target elements for the observations were used: a) time and activity, b) purpose, c) engaged materials, and d) reflection (Appendix D). In time and activity, I traced what activities occurred and how long students engaged in the activity. In purpose, I recorded the major purpose of the activity. In general, Mrs. Shelly explained the purpose or goal of each activity. In engaged materials, I recorded what kinds of materials were used for class activities. For example, in writing activities, students sometimes used pencils and paper, but often used computers. In reflection, I recorded my reflections regarding classroom observation. I also utilized other field notes to record informal conversations with students and Mrs. Shelly. In the notes, I recorded time and content of those conversations. In addition to these two sets of field notes, I utilized a modified RTOP rubric to score teaching performance. After returning from the research site, I scored Mrs. Shelly's teaching performance.

Non-Participant Observations

No one can observe everything. The researcher as an observer is limited in the ability to observe every activity and discourse engaged in by every student. Furthermore, critics of participant observation as a data-gathering technique point to the highly subjective and therefore unreliable nature of human perception, which is also very selective (Merriam, 2009, p.118). In this sense, the observer needed a framework for observation to make manageable the complex reality observed (Patton, 1990).

The major reasons to conduct observation in this study were as follows:

> a) (A)s an outsider an observer will notice things that have become routine to the participants themselves, things that may lead to understanding the contents… b) (T)o conduct observations is to provide some knowledge of the context or to provide specific incidents, behaviors, and so on that can be used as reference points for subsequent interviews…, and c) (P)eople may not feel free to talk about or may not want to discuss all topics (Merriam, 2009, p.119)

With these guidelines in mind, I had conducted participant observation in the participating teacher's science classes since the spring 2011 semester. The major reason I observed a participating science class before beginning data collection for this study was not only to build up a good relationship with the participating teacher, but also to understand how she used newly adopted science teaching approaches in her science classroom. Since students had science class every day and this study attempted to explore the development of students' understanding through discursive practice, I observed the science class daily.

The classroom observation allowed me to explore classroom contexts including how social interaction occurred between the teacher and her students, as well as between the students themselves, when classroom activities including investigation and teacher instruction, and discursive practices such as writing, reading, and talking occurred. I was also able to observe what the learning environment looked like. Class activities were largely guided by the phases of the SWH approach including beginning ideas, inquiry question, test, observation, claim and evidence, reading, and reflection. To capture students' engagement in scientific practice in a science classroom, the classes were also videotaped. Since the existence of a researcher and video camera could influence students' learning, during the first two weeks the researcher only observed and did not set up the video camera. After two weeks, the video camera was placed in the corner of the classroom to avoid distracting students from learning, and all science classes were videotaped.

Informal Conversation

This study did not include formal interviews with participants. Rather, I informally spoke with the teacher. The major purpose of this type of conversation is to listen to the teacher's voice to attain a better contextual understanding. Thus, informal conversation with the teacher was collected as data though these conversations were not recorded using a device such as a voice recorder. Instead, the researcher recorded informal conversations in the field notes to identify the purpose of activities in which students engaged.

To deepen the contextual understanding of the learning environment in which participants engaged, I also collected secondary data, including the semi-structured interview with the participating teacher and the teacher's modified RTOP scores. The semi-structured interview was conducted by a member of the SWH research team. In it, the interviewer asked about Mrs. Shelly's perspectives on learning, science, and pedagogy. In the RTOP scores, the researcher scored a total of 28 lessons based on the modified RTOP rubric. This secondary data was used to obtain a better understanding of the participants and to increase the trustworthiness of the study.

Data Analysis

Discourse Analysis involves "a careful scrutiny of all the linguistic devices employed by the persons who produced the discourse, taking into account the social and ideological setting of the discourse" to examine the intentionality and significance of language and its context (Wilson, 1993). There are three conventional branches of discourse analysis: a) the study of grammar beyond the sentence, b) the study of language in use, and c) the study of the rhetoric of power (Schiffrin, Tannen, & Hamilton, 2001). Among these three, this study focused on participants' language in use.

Discourse Analysis for this study was used to explore the development of Discourse students' understanding exhibited in participants' use of language. Thus, the primary goal of exploring students' use of language through Discourse Analysis was to investigate how participants make and develop meanings over time by engaging in scientific practice and how their discourses develop into the Discourse of science. Since language functions as both an epistemic tool and a tool of representation, examining students' use of language helped to explore not only the meaning students produced and developed through discursive practice (language as representation), but also the process of the development of meanings (language as an epistemic tool). In this sense, Discourse Analysis helped to clarify how students' use of language plays a role in the development of cognition through public and private negotiation.

Discourse Analysis for this study was two-fold. First, I analyzed six fifth grade students' writing samples to explore how individual students developed their cognition of science through writing as private negotiation, which addressed the first research question. In analyzing students' private negotiations, I focused on how six fifth grade students developed their understanding over time, and on how the written Discourse Space that each student created had changed during the process of the development of cognition. Second, I analyzed fifth grade students' speech to explore how students make meanings while engaging in public negotiation, which addressed the second research question. In analyzing students' public negotiations, I focused on how socially-structured meanings had developed over time in the Discourse Space students created, and on how the Discourse Space had changed during the process of the development of meanings.

Exploring Six Fifth Grade Students' Written Discourse

I analyzed samples of six fifth grade students' writing to explore how an individual student developed his or her understanding of science through writing as private negotiation, which addressed the first research question. Rivard and Straw (2000) found that "writing is an important discursive tool for organizing and consolidating rudimentary ideas into knowledge that is more coherent and well-structured" (p.586). In this regard, I explored how students generated their coherent stories of meanings within their own written Discourse Space.

To explore students' coherent stories that exhibited the development of cognition over time, the analysis of students' written discourse sought to identify how they shifted their "fuzzy" or unclear or unsubstantiated ideas regarding the ecosystem into the logically-clarified abstract explanation of the phenomena. To examine this shift, I explored the students' use of cognitive and linguistic resources that emerged in their written discourse over time. Drawing from Yoon, Hand and Villanueva (in press), examining the students' use of cognitive and linguistic resources was used to explore the embedded reasoning and their uses of sources in making meanings. To analyze students' writing, two senior researchers majoring in science education and a senior researcher majoring in communication were invited to examine the students' use of cognitive and linguistic resources and to check the appropriateness and credibility of the interpretations. In next sections, a way to examine the embedded reasoning was described first, and then students' uses of sources followed.

Complexity of reasoning

The embedded reasoning was examined by identifying the complexity of the reasoning. Since reasoning plays a key role in the accurate interpretation and production of science texts that are used as the main source of both the substantive content of science and of the interrelationships within in, improved reasoning skills can help students increase their literacy in a fundamental sense, which is central to scientific literacy (Norris & Phillips, 2003). Besides, exploring the embedded reasoning could respond to a call that many studies in arguments in the context of science education had pinpointed for creating a new approach to assess "the structural, conceptual, epistemic, and social aspects of argument generation in a more synergistic fashion" (Sampson and Clark, 2008, p.469). In the context of argumentation, reasoning served as fundamental skills not only to construct the structure or complexity of argument, and the content of argument, but also to justify how ideas or claims are supported or validated within an argument. With this in mind, examining the complexity of reasoning that emerged in students' texts could help not only to understand the development of students' understanding over time, but also to investigate the nature of quality arguments students generated in a more synergistic fashion.

For exploring student-generated reasoning, I first identified core meaning a single clause[4] represented. Then, I examined the connection between and arrangement of meanings. Since the process of making meanings or idea development helps students improve their cognition (Rogers & McClelland, 2004), this analysis aided in the exploration of how meanings that emerged in students' writing were built and developed. The connection between and arrangement of meanings was classified based on the functions. The function was defined by reasoning flow students generated through writing, and reflected a possible way students might experience as constructing and

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[4] I defined a clause as a group of related words containing a subject and a verb.

evaluating meanings. Once classified, the researcher identified how the clauses were linked together and then used this information to produce a graphical representation of the structure of reasoning if needed. This representation was helpful to visualize or demonstrate the complexity of reasoning an individual used in his or her writing and how the author coordinated the various meanings into a single story that represented his or her cognition.

The complexity of reasoning was distinguished into a *single reasoning*, a *chain of reasoning*, and a *reasoning network*. The complexity of reasoning was linked to the level of scientific explanation that students generated through writing, since their reasoning supported the growth of their scientific explanations (Yoon & Hand, 2012). To understand the growth of scientific explanation students constructed, I adopted Braaten and Windschitl's (2011) recent work to conceptualize the various levels of scientific explanation.

A *single reasoning* was identified as the fundamental reasoning unit that was used to generate a claim, conclusion, inference, or prediction with respect to natural phenomena. In previous research, this type of reasoning was primarily used to describe what happens. It could help to describe, summarize, or restate a pattern or trend in data, but could not make a strong connection to any unobservable or theoretical components as low levels of scientific explanation (Braaten & Windschitl, 2011). This *single reasoning* can be linked to one or more other *single reasonings*. This link extends a *single reasoning* to a *chain of reasoning* and *reasoning network*.

A series of *single reasoning* connections is a *chain of reasoning*. This is not to say that the arrangement of multiple *single reasonings* in a row is necessarily seen as a *chain of reasoning*. In a *chain of reasoning*, the topic with which preceding texts dealt should be developed by the connection between the preceding reasoning and the following reasoning. This development increases the complexity of reasoning by building up logical-semantic relations in texts through elaboration (i.e. using expository and exemplificatory relations), enhancement (i.e. using additive, alternative, and adversative relations), and extension (i.e. using temporal, causal, conditional, concessive, and comparative relations) (Halliday & Martin, 1993). Thus, disposition of multiple *single reasonings* without linking them cannot be seen as a *chain of reasoning*. A *chain of reasoning* helped students to describe how or partially why something happens. In terms of the level of scientific explanation that this type of reasoning created, the previous research showed that students started to address unobservable and theoretical components tangentially as a middle level of scientific explanation (Braaten & Windschitl, 2011).

A *reasoning network* comprises multiple *single reasonings*. Moreover, the *network* comprises multiple *chains of reasoning*. This *network* includes multiple perspectives to describe scientific concepts. Furthermore, the *network* explicitly presents the connections between those perspectives. When these connections are coherently and accurately related so as to build up scientific explanation, the description or explanation of natural phenomena can be advanced close to scientifically acceptable description or explanation. A *reasoning network* enabled students to explain why something happens. Students who utilized a *reasoning network* could trace a full causal story for why a phenomenon occurred, and started to use unobservable and theoretical components of a model to explain an observable event and phenomenon. Thus, they could use powerful scientific ideas to explain observable events, as a high level of scientific explanation (Braaten & Windschitl, 2011).

Example

The following example will help to demonstrate the process of exploring embedding reasoning that emerged in students' writing. This example was adopted from Yoon, Hand, and Villanueva (in press). Jordan, a fifth grade student, wrote down his ideas about the distance between the Earth and the sun while studying the unit Seasons. He wrote that:

> *I think that we are some light years away from the sun because if you go up in space just right out of the earth and you look up at the sun, it is very small. If you keep going just a small amount of distance, the sun still looks the same, but the earth doesn't look the same.*

For data analysis, I arranged Jordan's text according to the clauses of his sentences (see Table 3-3). Then, I examined the relations between clauses to understand the textual connections and integration used to develop meanings. In this example, Jordan begins by presenting his claim (clause 2) and then uses the following clauses to support his idea. The clauses involve two conditional speculations that follow an if/then/therefore pattern. He distinguishes the first and second speculations with respect to the position that "you," the reader, observe the Earth and the sun. Jordan did not explicitly state why the Earth is located "some light years away from the sun" (clause 2), but the use of the phrase indicates that he understands the great distance between the two solar bodies.

Table 3-4 Jordan's Writing Sample Arranged by the Clauses of his Sentences

Number	Clauses
1	I think that
2	we are some light years away from the sun
3	because if you go up in space just right out of the earth
4	and you look up at the sun
5	it is very small.//
6	If you keep going just a small amount of distance
7	the sun still looks the same
8	but the earth doesn't look the same.//

After understanding his reasoning, I visualized the reasoning structure and flows that Jordan's text exhibited. I identified the complexity of reasoning of this example as *single reasoning*. Figure 3-1 maps Jordan's single reasoning. His logical flows are denoted by arrows, and the dotted line indicates his implicit use of reasoning within the single line of reasoning, as noted by the rounded rectangle. The linking words were labeled by the researchers. In this example, Jordan exhibits a hypothetico-predictive reasoning structure (Lawson, 2003) in that he uses a hypothesis and imagined tests in clauses 3 and 6 to generate expected results/predictions (clauses 5, 4, 7, and 8). This process helped him to claim that "*we are some light years away from the sun.*" Jordan's claim was not scientifically acceptable, yet his text illustrated a single line of reasoning which enabled him to develop his ideas about distance. This single reasoning could produce a scientific account that focused on the question of what happened. Jordan focused on describing a pattern he imaginarily observed. However, this type of reasoning is not enough to explain the relation between distance and seasonal changes.

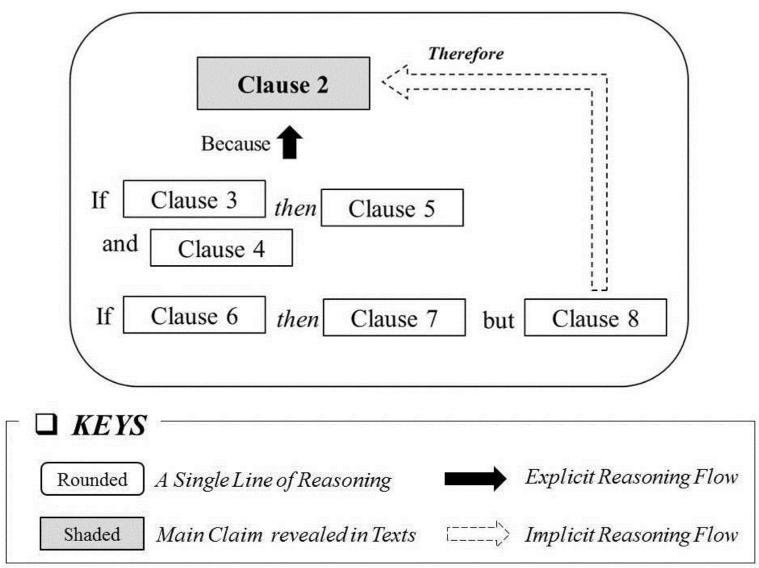


Figure 3-1. An example of the graphical representation of reasoning structure (Jordan's single reasoning)

Sources of meaning.

Sources used for making meanings were also explored. Students, as writers, constitute meaning by producing texts. Meaning in students' texts is not fixed, but rather is situated depending upon readers and contexts. In addition to the situated nature of interpreting texts, Halliday (2004) also suggests that students reshape their experience into language. In other words, producing texts does not merely involve encoding knowledge into written words; rather, texts represent writers' prior knowledge, experience, and perception. Therefore, students use privately-constructed and intuitive meanings as fundamental sources when producing texts. This kind of text is generated by the activation of type 1 processing that is characterized as heuristic and intuitive.

Scientists continuously generate scientific texts based on previously developed scientific language within science communities. In this process, critical review, evaluation, and critique occur. The meanings in scientific texts exhibit collective and collaborative features of scientific, not private, knowledge. Thus, scientific texts involve semantic relations among meanings in order to effectively represent underlying process, theory, speculation, and natural phenomena. Simply put, the sources of meaning in scientific texts are derived by semantic relations that are built by the analytic or reflective process that is observed in type 2 processing.

In this study, we classified two sources of meaning: private and scientific. To analyze sources of meaning, students' use of words was analyzed. These words exhibited linguistic components that students employed as they developed their idea of science in the course of ongoing embedded writing activities. The components included verbs, nouns, adverbs, and other grammatical elements. According to Eggins (1994), verbs are used to express *processes* of scientific concepts or natural phenomena, nouns are used to express *participants*, and adverbial or prepositional phrases are used to express *circumstance*.

Private sources of meaning are distinguished when words illustrate that the writers have projected themselves into the texts (as *participants*). These participants perceive and experience activities related to natural phenomena or events (as *processes*). The particular *circumstance* that writers describe in their texts seems to be derived from their daily lives. We identified other cases as reflective sources of meanings. For example, when texts exclude participants in describing natural phenomena and events, and only present a number of semantic relations, we recognize that writers have used scientific sources to build up meanings in their texts.

Example

I also used Jordan's writing (see table 3-3) as an example of this idea. Jordan used personal pronouns such as "I/We/You" as subjects of the sentences that described his ideas about the distance between the Earth and the sun. His words described himself ("I/We") and readers ("You") as the person who hypothetically observes the distance between the Earth and the sun in his imagined tests. He used casual, informal language such as "go up" and "look up" to describe the direction of the imagined texts, and adjectives and descriptive phrases, such as "some," "just right out of," and "just a small amount of." These phrases demonstrate vagueness (cf. Chafe, 1982) about the actual distance between these two bodies. The collection of casual, descriptive, and undefined phrases exemplifies how the student's privately constructed sources or everyday meanings and experiences were used to construct scientific meanings. However, Jordan dominantly used private sources to make meaning with respect to the distance between the Earth and the sun, which is characterized as cognitive artifacts generated by type 1 processing.

Table 3-5 Summary for Analyzing Students' Written Discourse

Complexity of Reasoning	Level of Scientific Explanation	Sources in Meaning Making
Single reasoning A fundamental unit for constructing and critiquing scientific account, which have a single argument supported by connections between a few ideas ***Chain of reasoning*** A series of single reasoning connection in order for elaboration, enhancement, and extension of argument that consists of connections between proceeding reasoning and following reasoning ***Reasoning network*** Complex cognitive network that comprises multiple single reasoning and multiple chains of reasoning, which include multiple perspectives to describe the natural phenomena by explicitly presenting connections between multiple ideas, reasoning, and representations	***Low level*** ▪ Presenting what happened ▪ Describe, summarize, or restate pattern or trend in data ▪ No connection to any unobservable/theoretical components ***Middle level*** ▪ Presenting how and partial why something happened ▪ Address unobservable/theoretical components tangentially ***High level*** ▪ Presenting why something happens ▪ Trace a full causal story for why a phenomenon occurs ▪ Connection between observable event or phenomenon and unobservable and theoretical components by using powerful science ideas and models	***Private source*** ▪ Type 1 processing (Intuitive) related ▪ Intuitively constructed ▪ Close to colloquial language ***Scientific Source*** ▪ Type 2 processing (Reflective) ▪ Semantically related ▪ Close to scientific texts

Exploring Fifth Grade Students' Spoken Discourse

The goal of examining students' spoken discourse was to explore how fifth grade students make meanings while engaging in public negotiation, which addressed the second research question. In analyzing students' public negotiations, I focused on how socially-structured meanings had developed over time in the Discourse Space students created, and on how the Discourse Space had changed during the process of the development of meanings. I explored fifth grade students' use of language in terms of what situation, what purposes, and in what ways participants used language to engage in discourses which emerged in a science classroom. Furthermore, I examined texts that students produced while immersed in the Discourse Space by questioning how these texts were interconnected to make meanings, and how participants took their position in the Space. This analysis focused on the ways in which students develop discourses into a level of the Discourse of science. In this sense, discourse was analyzed based upon five components of discourse, drawing from the researcher's (2009; 2010) earlier work. These five components included context, purpose, strategy, text, and position, and were closely interconnected and intertwined when students used language to make meanings for the development of cognition. Figure 3-2. shows the relationship of the five components.

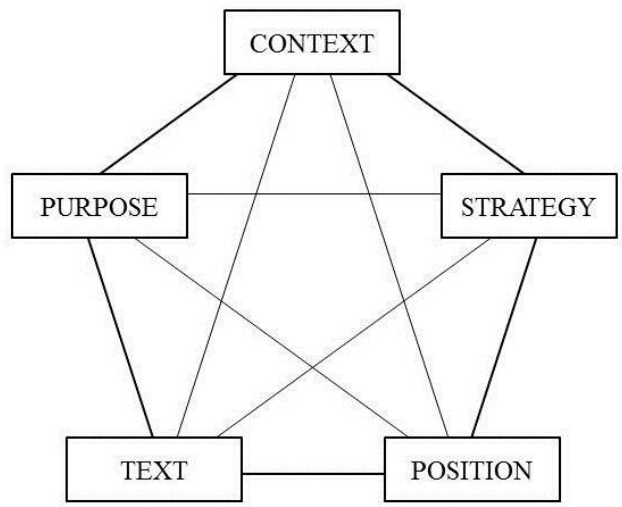


Figure 3-2. Five components of Discourse

Gee (1999) proposed seven building tasks that play a crucial role in Discourse Analysis. These seven tasks are significance, activities, identities, relationships, politics, connections, and sign systems and knowledge. They portray the reality of discourse that people "always and simultaneously construct or build as engaging in talking and writing (Gee, 1999). Differing from Gee's (1999) seven building tasks, the model in figure 2 presents five components of discourse that are hierarchically structured. These five components do not aim to reconstruct the reality that participants in discourse might experience while engaging in talking and writing. Rather, they were used to explore meanings that were represented through language as cognitive artifacts that participants socially or individually developed. Therefore, this model focused more on the exploration of the epistemic nature of meaning-making processes than on the ontological nature, which aims to exhibit the reality. Following are descriptions of each category.

Context

The category of context referred to a situation of action. Contexts were deeply embedded within discursive activities and emerged with discourse itself (Linell, 1998). The students' use of language was always situated. The meanings students generated through using language, therefore, were also situated. The first component of discourse was the context that informed the situations students went through while using language at a certain time. In this study, a context was understood as fluid, not as fixed. Therefore, it was important to illustrate the changes in contexts to portray the epistemic nature of the meaning-making process. In this regard, the category of context helped to convey the ongoing changes of the situation while students engaged in language practice as part of scientific practice.

Purpose

The category of purpose referred to a goal of action. When students engaged in negotiation, they were guided by various purposes, aims or goals. Students' utterances had diverse purposes depending on the context in which they occurred. Although it might be difficult to argue that each single utterance always exhibited a specific purpose of action, examining a series of utterances and sentences helped to illustrate the speakers' or writers' purpose. In this study, I categorized the purpose of students' utterances into seven components as follows: a) initiating ideas, b) sharing ideas, c) reflecting ideas, d) seeking ideas, e) elaborating ideas, f) exploring ideas, and g) evaluating ideas. These seven purposes were categorized in terms of idea development. Each purpose was not seen as totally separate. In addition, purposes were seen as occurring at two levels: global and local. For example, during the first day of the unit on Seasons, students shared their ideas about seasons. In this context, students could share their ideas to achieve the goal of initiating ideas, or initiate their ideas to achieve the goal of sharing ideas. Given the fact that this was the first day of the unit, it might be possible to say that the students' global purpose was to initiate ideas even though sharing ideas could also be seen as the purpose of the action. In this situation, this study viewed sharing ideas as the *local purpose* and initiating as the *global purpose*.

Strategy

The category of strategy referred to a plan of action. This category was identical to the category of purpose. Plans were not limited to modes and types of utterance. For example, questioning as a type of utterance could be seen as a strategy. Similarly, when a student used her gesture to ask a question, the gesture as a mode of utterance could be seen as a strategy. From this point, this study limited sub-categories for *Strategy* into language levels. I used seven sub-categories: a) demanding to explain or justify previous utterances, b) supporting previous utterances, c) defending previous utterances, d) rejecting previous utterances, e) revisiting previous utterances, f) changing the direction of previous utterances, and g) articulating previous utterances. Of course, there were a wide range of other possible categories such as using materials, relying on authority, initiating a new topic, and so on. However, this study only utilized seven sub-categories of *Strategy* to explore the development of cognition that emerged in Discourse Space.

Text

The category of text referred to representations of action. This study did not limit text to written texts. Rather, texts included all kinds of language that could be used to make meaning. Since discourse involves building and using fragments of understanding and contexts (Linell, 1998), exploring students' use of language at a textual level helped to explain the process of meaning-making they generated as participants in discourse. A representing meaning within a text could incorporate other meanings by different texts in a variety of different ways. Participants in discourse might share and incorporate the texts that represented meaning for achieving a particular goal. This process of incorporating meanings contributes to constructing identity, knowledge, discourse, or even culture. Gee (1999) called this process *intertextuality*. Although this analysis did not use intertextuality to trace the original source of meanings, the fundamental concept of intertextuality was used to explore the epistemic nature of discourse. Thus, the researcher examined the connection between and arrangement of meanings, so that analyzing texts meant moving beyond examining the semantic relation between them.

Since engaging in the process of making meanings or idea development helped students to develop their cognitive abilities, arisen from experience (Rogers & McClelland, 2004), I explored how students built and developed meaning while engaging in discursive practice. Throughout the discursive practice, students started to build larger patterns and trends linked to one another beyond simple semantic relations. These larger patterns and trends can be identified as the big ideas of a topic, which can be seen as a thematic pattern drawn from Lemke (1990). To create better and more plausible semantic relation and thematic patterns, students might need to practice a specific skill via language practice, termed *reasoning*. In this regard, this category focused exclusively on how students' reasoning had been developed while engaging in public and private negotiation based on the fundamental idea of intertextuality.

<u>Position</u>

The category of position referred to the position of the actor as immersed in discursive practice. Discursive actions are always contextualized for and by the actors (Linell, 1998). Students as actors of discourse build their understanding of natural phenomena while engaging in discursive practice. Rogoff also noted:

> Children's participation in communicative processes is the foundation on which they build their understanding. As children participate in ongoing activities, they adjust to the social sense of their partners and incorporate the skills and perspectives of their society. As they are assisted in problem solving, they are involved in the views and understanding of the skilled partner, in the process of stretching their concepts to find a common ground; as they collaborate and argue

> with others, they consider new alternatives and recast their ideas to communicate or to convince. (Rogoff, 1990, p.196)

In this study, I explored how students participated in discourse to develop their cognition through using language and how they interacted with the development of Discourse Space by becoming a participant in discourse.

In summary, I analyzed students' speech to explore how they make meanings while engaging in public negotiation, which addressed the second research question. In analyzing students' public negotiations, I focused on how socially-structured meanings had developed over time in the Discourse Space students created, and on how the Discourse Space had changed during the process of the development of meanings. In Discourse Analysis, five components of discourse were emphasized: a) context, b) purpose, c) strategy, d) text, and e) position. Table 3-5 summarizes the ways to analyze students' spoken discourse.

Table 3-6 Summary for Analyzing Students' Spoken Discourse

Category	Definition	Focus
Context	a situation of action	*What activities did students engage in before and now?*
Purpose	a goal of action	*What was the major purpose of the activity students engaged in?* *Ex) a) Initiating ideas* *b) Sharing ideas* *c) Reflecting ideas* *d) Seeking ideas* *e) Elaborating ideas* *f) Exploring ideas* *g) Evaluating ideas.*
Strategy	a plan of action	*What resources were used to help students perform the activity?* *Ex) a) Demanding to explain or justify previous utterances* *b) Supporting previous utterances* *c) Defending previous utterances* *d) Rejecting previous utterances* *e) Revisiting previous utterances* *f) Changing the direction of previous utterances* *g) Articulating previous utterances*
Text	representations of action	*In what ways were meanings incorporating for constructing identity, knowledge, discourse, or even culture?*
Position	the position of the actor	*What was the role of students as participants while performing the activity?*

Summary

Discourse Analysis for this study was used to explore the development of Discourse Space that was exhibited in participants' use of language. Thus, the primary goal of exploring Discourse Space through Discourse Analysis was to investigate how participants make and develop meanings over time by engaging in scientific practice and how their discourses develop into the Discourse of science. Discourse Analysis for this study was two-fold. First, I analyzed fifth grade students' speech to explore how they make meaning while engaging in public negotiation, which addressed the first research question. In analyzing students' public negotiations, I focused on how socially structured meanings had developed over time in the Discourse Space they created, and how the Discourse Space had changed during the process of the development of meanings. Students' spoken discourse was explored based on five components. This analysis aimed to unpack the process of meaning-making while students as members of a community participated in public negotiation, and five components of discourse were emphasized: a) context, b) purpose, c) strategy, d) text, and e) position.

Second, I analyzed six fifth grade students' written discourse in an attempt to explore how these students developed their cognition through writing as private negotiation over time. This addressed the second research question, since written discourse aimed to consolidate knowledge rather than to contribute to the distribution of knowledge like spoken discourse (Rivard & Straw, 2000). In analyzing students' private negotiations, I focused on how these six fifth grade students developed their understanding over time, and on how the written Discourse Space that each student created had changed during the process of the development of meanings. This analysis explored linguistic and cognitive resources that emerged in the students' texts by examining the embedded reasoning and the sources of meaning inherent in texts that students produced in the science classroom.

Trustworthiness of the Study

Quantitative researchers have clearly established concepts such as reliability and validity, and strategies serving as guidelines for ensuring the quality of their studies. These concepts and strategies allow quantitative researchers to deal with the issue of objectivity (Creswell, 1998, 2003; Rubin & Babbie, 2005), and the concepts of validity and reliability can be seen as the main means of establishing rigor. However, these two measures are not applicable standards for qualitative studies. Lincoln and Guba (1985) discussed the concept of *trustworthiness*, and suggested criteria that corresponded to the criteria employed by the quantitative researchers. As a result, credibility, transferability, dependability, and confirmability have become widely adopted in qualitative research as substitutes for internal validity, external validity, reliability, and objectivity (Lincoln, 1995; Merriam, 2009).

Lincoln and Guba (1985) suggested that trustworthiness is established when findings as closely as possible reflect the meanings as described by the participants. However, Padgett (1998) explains that trustworthiness is not something that just naturally occurs, but instead is the result of "rigorous scholarship" that includes the use of defined procedures (p.92). Based on these ideas, I adopted a set of standards and strategies suggested by Merriam (2009) and Shenton (2004), which helped to ensure the quality of the study.

Credibility or Internal Validity

Internal validity deals with the question of how research findings match reality. Credibility corresponding to internal validity was defined as "something other than reality itself" (Lincoln & Guba, 1985). Moschkovich and Brenner (2000) defined credibility as "how well the results capture the constructs used by the participants in a context and the particular dynamics of that context" (p.479). This view of reality is based on one of the assumptions of qualitative research that "reality is holistic, multidimensional, and ever-changing, it is not a single, fixed, objective phenomenon waiting to be discovered, observed, and measured as in quantitative research" (Merriam, 2009, p.213). Due to these features, several strategies suggested by qualitative researchers (e.g. Lincoln & Guba, 1985; Stake, 1995) were needed to assure credibility, and I used multiple strategies summarized by Shenton (2004).

Development of early familiarity with the culture of participating organizations

Early familiarity can be developed by "consultation of appropriate documents and preliminary visits to the organizations themselves" (Shenton, 2004, p.65). For this study, I had visited and observed the participating teacher's science class a semester before data collection was carried out. This helped to build a positive relationship and to obtain a better understanding of the contexts of participants, school, and community. To avoid distortion that might occur due to unusual events, such as the presence of the researchers and a video camera, I had attended the participating teacher's science class every day for two weeks before data was collected. In addition, during the first two weeks of the first unit, I did not use a video camera to record student learning. After a month, I started to use the video camera but placed it in the corner of the classroom to avoid distracting students from learning. Even once all the primary data had been collected, I kept visiting the class once or twice a week not only to attain a better understanding of the participants and their culture, but also to support the students' learning. It helped to have a "prolonged engagement" between the investigator and the participants in order both for the former to gain an adequate understanding of the organization and in order to establish a relationship of trust between the parties, which Lincoln and Guba (1985) and Erlandson, Harris, Skipper, and Allen (1993) have recommended.

Triangulation

Although the major purpose of qualitative research is not and cannot capture an objective truth or reality, to increase "the correspondence between research and the real world" (Wolcott, 2005, p.160), many qualitative researchers use a well-known strategy called triangulation. In this study, I used strategies including multiple methods and multiple sources of data suggested by Denzin (1978). Multiple sources of data used included observation, informal conversation, writing samples, and researcher's field notes as the primary data, and teachers' modified RTOP scores and semi-structured interviews with the teacher as the secondary data. In addition, this study adopted Discourse Analysis as the fundamental method, but used two different approaches based on the type of discourse: speaking and writing. The findings drawn through these different analysis methods were compared and integrated through triangulation.

This triangulation exists not only for confirmation and validation, but also for differentiation (Flick, 2002). Not all meanings can be resolved. When differentiation was highlighted, I could learn about different views that should be examined closely. This process helped me to recognize that the situation was more complex than I had first realized, so that I learned there were more meanings to unpack. As such, using multiple sources of data and methods helped not only to make me more confident when seeing multiple meanings, but also provided more credible evidence.

Debriefing sessions between researcher and superiors

I frequently conducted debriefing sessions with colleagues who visit the same school and with my supervisor. The purpose of debriefing sessions was to obtain a better understanding of the phenomena that I observed by listening to others who brought to bear their own experiences and perceptions on the situations. Shenton (2004) described how debriefing sessions help to assure credibility as follows:

> Such collaborative sessions can be used by the researcher to discuss alternative approaches, and others who are responsible for the work in a more supervisory capacity may draw attention to flaws in the proposed course of action. The meetings also provide a sounding board for the investigator to test his or her developing ideas and interpretations, and probing from others may help the researcher to recognize his or her own biases and preferences. (p.67)

Examination of previous research to frame findings

Silverman (2000) emphasized that the ability of the researcher to relate his or her findings to an existing body of knowledge is a key criterion for evaluating works of qualitative inquiry. Shenton (2004) suggested that reports of previous studies staged in the same or a similar organization and addressing comparable issues may be invaluable sources (p.69). In this regard, I designed this study based on a preliminary study that focused on fifth grade students' development of understanding through writing while immersed in a language-based argument inquiry approach. In other words, this study used the same or similar situations as the previous study. Therefore, this study examined the previous research not only to frame findings, but also to expand on those findings.

The researcher's "reflective commentary"

The researcher's reflective commentary can help to present critical self-reflection regarding assumptions, worldview, biases, theoretical orientation, and relationship to the study that may affect the investigation (Merriam, 2009). In this study, I used reflection field notes to record my initial impressions of each data collection, patterns appearing to emerge in the data collected, and theories generated.

Transferability or External Validity

External validity is concerned with "the extent to which the findings of one study can be applied to other situations" (Merriam, 2009, p.223). However, in general, the findings of a qualitative project are specific to a small number of particular environments and individuals, so that it might be impossible to demonstrate that the findings and conclusions are applicable to other situations and populations (Erlandson, Harris, Skipper, & Allen, 1993). In this sense, based on Lincoln and Guba's (1985) argument, Firestone (1993) maintained that since the researcher knows a specific context, he or she cannot make transferability inferences. In other words, it is not the researcher's task, but the reader's, to decide whether and how the results may be relevant to his interested topic or context. Thus, transferability is not a simple techinique to generalize results, instead may help readers to determine whether the findings are transferable.

Qualitative researchers have suggested several strategies that can be employed in qualitative study to enhance the possibility of the results of the study "transferring" to another setting: rich, thick description and purposeful sampling (Merriam, 2009). In this study, I described the research context in a rich and thick manner as suggested by Shenton (2004, p.70) as follows: a) the number of organizations taking part in the study and where they are based; b) any restrictions on the type of people who contributed data; c) the number of participants involved in the fieldwork; d) the data collection methods that were employed; e) the number and length of the data collection sessions; and f) the time period over which the data was collected. In addition, purposeful sampling enhanced transferability since it allowed for "the possibility of a greater range of application by readers or consumers of the research" (Merriam, 2009, p.227). In this study, I provided a detailed description of the process of selecting participants as that process corresponded to the research questions.

Dependability or Reliability

Reliability refers to the extent to which research findings can be replicated (Merriam, 2009, p.220). However, many qualitative researchers have noted that conventional notions of reliability are problematic in qualitative research (e.g. Marshall & Rossman, 1999; Merriam, 2009) since this research developed based upon a different fundamental foundation than quantitative study, which focuses on discovering causal relationships among variables and uncovering laws to explain phenomena. Thus, the more important question for qualitative research is whether the results are consistent with the data collected (Merriam, 2009, p.221). In this context, Lincoln and Guba (1985) conceptualized reliability as “dependability” or “consistency.” To ensure consistency and dependability, qualitative researchers have suggested several strategies. Merriam (2009) summarized four strategies including triangulation, peer examination, investigator’s position, and the audit trail. The three strategies of triangulation, peer examination, and investigator’s position have already been discussed under credibility: triangulation, debriefing sessions between the researcher and his superiors (or peer examination), and the researcher’s “reflective commentary” (or investigator’s position).

The audit trail is a method suggested by Lincoln and Guba (1985). This method aimed to provide a detailed account of the methods, procedures, and decision points in carrying out a study (Merriam, 2009). In this study, I provided a detailed account of: a) the research design and its implementation, b) the operational detail of data gathering, and c) reflective appraisal of the project, suggested by Shenton (2004, pp.71-72). This detailed account helped readers understand how data were collected, how categories were derived, and how decisions were made throughout the inquiry.

Confirmability or Objectivity

The concept of confirmability is the qualitative investigator’s comparable concern to objectivity. It is occupied with how well the biases of the researcher could be eliminated in the process of research. In this study, I employed reflective journal writing that was used as the researcher’s “reflective commentary” under credibility and the “investigator’s position” under dependability. As Patton (2002) pointed out, it is difficult to ensure real objectivity; because even tests and questionnaires are designed by humans, the intrusion of the researcher’s biases is inevitable. In addition to reflective journal writing, using an audit trail, which was also employed to assure dependability, allowed any observer to trace the course of the research step-by-step via the decisions made and the procedures described (Shenton, 2004). In this regard, I used reflective commentary and audit trail as strategies to assure confirmability by admitting the researcher's beliefs and assumptions, recognizing the shortcomings of the study's methods and their potential effects, and providing in-depth methodological description to allow the integrity of the research results to be scrutinized.

Summary of Chapter

This study aimed to explore students' development of cognition through writing and the pattern of Discourse Space development that emerged in students' written and spoken language. It employed a generic qualitative study. Major data sources included students' writing samples, informal conversations with the teacher, researcher's field notes, and classroom videos. Additionally, the teacher's modified RTOP scores and semi-structured interviews were used to deepen the contextual understanding of the learning environment and the teacher's instructional performance. The data analysis was conducted by utilizing discourse analysis of writing and talking. A set of standards and strategies such as purposeful selection of the students, development of early familiarity with the culture of participating organizations, triangulation, debriefing sessions between the researcher and superiors, examination of previous research to frame findings, and the researcher's "reflective commentary" all helped to enhance the credibility, transferability, dependability, and conformability of the study.

CHAPTER FOUR

FINDINGS

This study aimed to explore students' development of cognition through writing and the pattern of Discourse Space development that emerged in students' written and spoken language. In this chapter, I describe findings related to these areas. This chapter consists of two sections. First, I examine the changing patterns that emerged in students' use of written language over time. Second, I discuss verbal discourse patterns that appear when students engage in three different contexts. All teachers' and students' names used in this study are pseudonyms.

Changes in Patterns that Emerged in Students' Use of Written Language Over Time

This research mainly examined the reasoning complexity and students' use of sources for making meaning. To further explore pattern changes, the physical time students engaged in diverse classroom activities and the purpose of writing assigned by the teacher were also analyzed. The researcher's field note helped not only to trace the physical time in which students engaged in diverse classroom activities including writing tasks, but also helped to elucidate the purpose of each writing task. Informal conversation with the teacher also helped to identify the purpose of each writing task. Data analysis focusing on students' written discourse revealed changes of patterns that emerged in their use of written language over time in two aspects: a) Students' reasoning developed over time and b) Students' use of sources for making meaning changed depending upon contexts. To attain a better understanding of patterns that emerged in students' written discourse, the pattern of the development of students' written Discourse Space was also described. In this section, students' reasoning development over time is described first, followed by a discussion of the changes in the students' use of sources for making meaning.

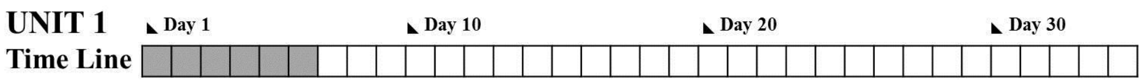
Reasoning Development Over Time

Finding 1: All six students' reasoning skills developed over time.

Reasoning plays a key role in the accurate interpretation and production of science texts that are used as the main source of both the substantive content of science and of the interrelationships within it (Norris & Phillip, 2003). According to this argument, students' development of reasoning through writing over time could help the development of their understanding of science. The data analysis indicated that participating students' reasoning skills developed over time. The level of reasoning complexity that emerged in six fifth grade students' writing samples varied, but in general developed from "undeveloped reasoning" to "chains of reasoning" throughout a unit.

In the following section, I further substantiate/explain the finding that students' reasoning became more complicated over time. Depending upon the reasoning complexity that emerged in students' texts, four phases were identified as follows: a) fuzzy understanding, b) seeking alternatives, c) toward comparing ideas, and d) comparing and consolidating ideas. Each phase is described based on the levels of explanatory power and the changes in patterns of Discourse Space. Students' writing samples were used to illustrate the development of reasoning complexity.

Phase 1: Fuzzy understanding: "*When I closed my eyes the first thing that was in my mind…*"



- Used Writing Samples on Days 1-6
- Activities: Presenting Big Idea of the Unit, Concept Mapping, Inquiring Questions, Teacher Reading (The Given Tree), Writing, Group Work, Whole Class Discussion

On day 1, Mrs. Shelly presented the big idea that students were supposed to learn throughout this unit by writing it down on the white board. The big idea was that living things interact with and depend upon one another and their environment. The lesson began with interpreting what this sentence meant. Mrs. Shelly led class discussion by using a triadic pattern of dialogue to share students' ideas about the meanings of each major word: "living thing," "non-living thing," "environment," "interact," and "depend." Students came up with diverse ideas related to the words. In an informal conversation with Mrs. Shelly after the class was finished, she informed me that she did not aim to elaborate the students' understanding of meanings in detail at that moment. Instead, she wanted them to share their initial ideas, which might help them create the concept map that was the major activity for that day [Informal conversation (IC) with Mrs. Shelly, Day 1]. After five minutes of class discussion, Mrs. Shelly read a book, *The Giving Tree*, by Shel Silverstein. The story was about a friendship between a boy and a tree, and offered "an affecting interpretation of the gift of giving and a serene acceptance of another's capacity to love in return" (from the author's website: http://www.shelsilverstein.com/html/books.asp). The teacher read this book as the beginning activity not only to improve students' engagement, but also to initiate their ideas with respect to ecosystems [IC with Mrs. Shelly, Day 1]. After reading, students took part in a short classroom discussion to share their ideas about the story. Then, Mrs.

Shelly asked the students to write about what an ecosystem is. Students' writing samples indicated their initial ideas about ecosystems.

The data analysis indicated that all six students' writing samples exhibited their fuzzy understanding. Ruby's writing sample nicely captured her fuzzy understanding with respect to ecosystems as follows:

> When I closed my eyes the first thing that was in my mind was about Eart [Earth]* and the planets that are around Earth. Like the soloar [solar] system thats [that's] what I was thinking about. The tree gave the boy things, but the boy never gave anything back for exchange. The tree gave him shade to sleep under, braches to swing on, leafs and branches to make a house, and the trunk to make a boat but the boy gave the tree nothing back for exchange. But the tree and boy helped each other live. [Ruby (L), Notebook (NB), Day1]
> **Brackets indicate researcher's correction of students' misspelled words.*

Ruby was one of the participants in the low level group, and this example contains the initial ideas that she wrote in her notebook on day 1 of this unit. Based on the contents of the text she produced, her writing was divided into two parts. The first part was understood as her initial inference regarding ecosystems. Her narration that started with "When I closed my eyes the first thing that was in my mind was" indicated that her ideas came from her intuition, rather than from comprehensive reasoning. The second part of this writing described the story of The Giving Tree, which Mrs. Shelly read to the class. Ruby described and summarized what she heard, but did not yet explicitly connect her description of the story to her beginning ideas about ecosystems. This pattern also appeared in other students' writing samples. For example, Michael wrote that:

> I thought of ants. They work together. Bees, too. I thought that you shouldn't just take things. The boy didn't give anything to the trees. Trees help us, we help them. Don't be selfish. Don't take for granted. [Michael (H), NB, Day 1]

Michael was a participant in the high level group. Similar to Ruby, his writing consisted of two parts. The first three sentences indicated his initial inference, and the following sentences included contents related to the story. A similar pattern was identified in Megan's writing sample. She stated her initial ideas about ecosystems as follows:

> Ecosystem is like the whole entire earth or environment. Plants are important to the plant [planet] other than oil and gas. [Megan (M), NB, Day 1]

Megan was a participant in the medium level group. Differing from other students, she did not explicitly discuss the story that Mrs. Shelly had read out loud. However, the contents of the second sentence implied that her idea seemed to have been initiated by the story since the sentence began with the word "plants," which could be linked to the tree in the story. It was also possible that Megan chose this word as an example to demonstrate an ecosystem. However, considering the relation with the previous sentence and the meanings that the sentence presented, it could be argued that the second sentence implied her ideas associated with the story. Moreover, from a linguistics viewpoint, in the sentence there was a point of departure of the clause, called a theme, which is thought of as the idea represented by the constituent at the starting point of the clause (Bloor & Bloor, 2004). In this regard, the word "plants" would be understood as the key idea that led the sentence. Thus, unless Megan used this word for a particular reason, there was a higher possibility that her selection of words might have been influenced by contextual cues such as others' previous utterance or words that were frequently discussed. Given the fact that the writing task occurred immediately after the teacher's reading, it could be argued that the story seemed to exert a large influence on Megan's ideas in the second sentence. The previous analysis indicates that the three students' writing samples showed similar patterns: a) presenting initial inference, and b) describing their ideas based on the story.

There was, however, no explicit connection between these two parts. In the first part, students' intuitive inferences appeared. For example, Ruby's writing sample explicitly indicated this initial inference since she began her ideas with the phrase, "When I closed my eyes the first thing that was in my mind was…". This implied that she explicitly expressed what she initially and intuitively thought about ecosystems through writing. Although the following sentence functioned to specify her inference, it did not elaborate or expand on her ideas as revealed in the previous sentence. Therefore, I argue that although Ruby engaged in cognitive processes that could not be identified, the major goal of the cognitive processes was to express or generate her initial inference, rather than to elaborate or develop her ideas about ecosystems.

This could be aligned with Michael's first sentence, which began "I thought of…". Although he did not elaborate his ideas, his sentence illustrated that his initial ideas about ecosystems captured one of their features, which was represented by his expression of "working together." Ants and bees were examples to exhibit the interaction between living things. He began with presenting an example, "I thought of ants," and then specified why he thought of ants, "They work together." Then another example was added, "Bees, too." Michael's sentences entailed a slightly different pattern from Ruby's, but indicated that the ideas presented by his written texts were his initial and intuitive inferences.

Megan's writing sample might be examined differently, but I argue that her text involved a similar pattern. The theme of her sentence was "ecosystem," which was a prompt that Mrs. Shelly suggested the students write about. She began with the prompt as the starting point to express her ideas about ecosystems. With this in mind, her way of expressing her initial thought seemed similar to Michael's. She described an ecosystem as "like the whole entire earth or environment." This could be understood as another feature of ecosystems differing from the feature Michael described, but it could be argued that through writing, Megan expressed what she initially thought when she heard the word or prompt “ecosystem.”

The three students’ writing styles varied. However, the pattern of making meaning through writing appeared to be similar. Just as Ruby’s statement “When I closed my eyes the first thing that was in my mind was…” presented, I argue that the students expressed their initial ideas about ecosystems. This process was relatively quick and intuitive, corresponding to type 1 processing in dual-process theory. Ruby might have imagined or visualized the Earth in her mind, Michael imagined ants or bees, and Megan imagined the entire earth or environment. Then, they expressed those ideas through writing. Since this writing occurred on day 1 and students were engaging in their first short writing task, they had not yet had enough opportunities both to build their own ideas and to evaluate those ideas. In this sense, the reasoning that emerged in the written texts was undeveloped and unstructured. The students’ understanding, therefore, could be classified as fuzzy at that point of time. This fuzzy understanding did not infer that the students were incapable of understanding the topic, or that they did not engage in any cognitive processes at that moment. Instead, the students engaged more in generating their initial inferences through relatively quick cognitive processes. As a result, their writing samples exhibited fuzzy understanding represented by their undeveloped reasoning.

Expansion, but no development

The participants’ writing from day 1 to day 6 exhibited their fuzzy understanding. While engaging in social interactions, students had more opportunities to use diverse cognitive and linguistic resources prompted by activities such as group and whole class discussion for concept mapping and composing inquiry questions. This influenced the expansion of students’ use of words or ideas, but the data analysis indicated that there appeared to be no corresponding development in reasoning.

Students' writing on day 1, presenting their initial ideas about ecosystems, consisted of an undeveloped reasoning that indicated their fuzzy understanding. Based on their own beginning ideas, these students, however, started to build up their understanding by engaging in multiple activities. The following examples exhibited the development of six students' understanding through writing that occurred from day 1 to day 6. Before illustrating these examples, I first describe the contexts in which writing activities occurred.

During this phase from day 1 to day 6, students engaged in two main activities that included concept mapping and creating inquiry questions. In the concept mapping activity, students were encouraged first to make concept maps within their groups, and then to collaboratively build up a class concept map. Mrs. Shelly indicated in an informal conversation that she thought of this as a "useful activity to initiate students' ideas" [IC with Mrs. Shelly, day 2]. In an activity involving inquiring questions, Mrs. Shelly asked students to individually come up with three questions and to work with group members to elaborate their ideas and articulate the language of the questions. Questions posed by each group were evaluated by the whole class on the basis of the criterion of whether the question was testable or researchable. Through whole class discussion, only testable questions were considered as possible questions for students to investigate further.

The data analysis showed that the six participants built their ideas over time based on their initial inferences. For example, Michael's initial inference regarding ecosystems was that "work[ing] together" was the major mechanism of an ecosystem, and that "ants and bees" were an example of an ecosystem [NB, Michael (H), day 1]. His inference kept developing as he engaged in social interactions including small group work and whole class discussion. Following is his day 2 writing:

> Community was good for what our big idea is. Enviroment [environment] is kind of the same thing as ecosystem. Plants and animals help each other. Plants feed some animals. They feed bigger animals, and then the biggest animal eats them. [NB, Michael (H), day 2]

In this writing, Michael used new words including “community,” “environment,” and “plants and animals” to describe ecosystems. These new words were interpreted as his selection to make meanings among many ideas that included linguistic and cognitive resources. In other words, the data analysis and observation highlighted that Michael did not just use words from a list. Instead, he participated in the discussion and chose the best words to present his ideas at that moment.

Examining the context of day 2 before the writing activity, students engaged in whole class discussion. In the discussion, students brought up and shared lots of information. Mrs. Shelly made a list of these diverse ideas about the ecosystem on the white board to help students create their concept maps. For example, students brought up the words “animals” and “plants” as examples of ecosystems, and those were classified as examples of living things through whole class discussion [Field note (FN), day 2]. Figure 4-1 shows the final version of the whole class concept map arranged by Mrs. Shelly that indicated the ideas that were shared and discussed during class discussion on day 2.

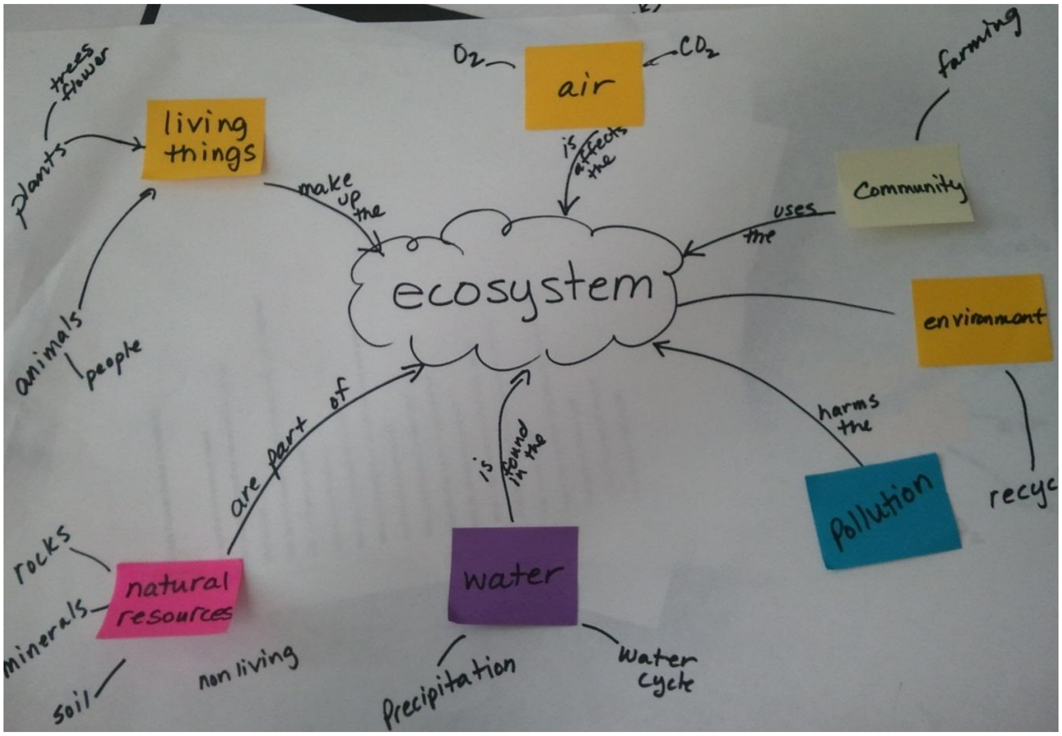


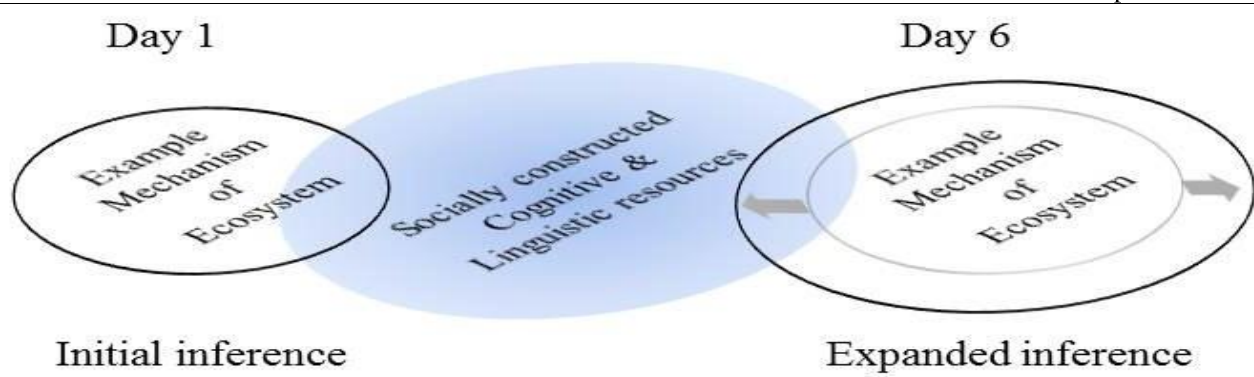
Figure 4-1 The class concept map on day 2 recorded by Mrs. Shelly

Based on these ideas, students started to pose questions for their investigation. From day 3 to day 5, they engaged largely in the activity of posing inquiry questions to classify testable and researchable investigation. On day 6, Mrs. Shelly asked students to write about their current knowledge of ecosystems before deciding the investigating question for each group's experiment. Following a prompt, "My knowledge of the ecosystem is" suggested by the teacher, students wrote down their current knowledge about ecosystems. Following is Michael's description of his current knowledge:

> My knowledge of the ecosystem is how things work together. Things always seem to help each other out. We couldn't live without team work. It is one of the most important things in life. It's also all the plants and animals. [NB, Michael (H), day 6]

In this writing, Michael's initial inference from day 1 seemed not to have changed much. Considering the contents of his texts, his writing illustrated similar ideas about the examples and mechanisms of ecosystems. However, these examples had changed from specific objects such as "ants and bees" to broad objects such as "plants and animals." It could be argued that this change was influenced by his engagement in social interactions on day 2. Michael's description of the mechanisms of ecosystems was also expanded to include more ideas such as "help each other" and "team work." Table 4-1 shows the process of expansion in describing his ideas about ecosystems.

Table 4-1 Fuzzy Understanding that Emerged in Michael's Writing Samples from Day 1 to Day 6

	Day 1	Day 1	Day 2	Day 6
Pre-context	Teacher reading	Small group discussion	Class discussion & Concept map	Inquiring questions & Concept map
Purpose	Initiating ideas	Initiating ideas	Reflecting ideas	Reflecting ideas
Reasoning Complexity	Undeveloped Reasoning			
Writing	*I thought of ants. They* ***work together****. Bees Too. I thought that you shouldn't just take things. The boy didn't give anything to the trees. Trees help us, we help them. Don't be selfish. Don't take for granted.*	*We talked about how we* ***work together****. Alsow [also] how the ecosystem works and why we work together. We talked about improving what we said about the ecosystem.*	***Community*** *was good for what our big idea is.* ***Enviroment*** *[environment] is kind of the same thing as ecosystem.* ***Plants and animals help each other****. Plants feed some animals. They feed bigger animals, and then the biggest animal eats them.*	*My knowledge of the ecosystem is how things* ***work together****. Things always seem to* ***help each other*** *out. We couldn't live without team work. It is one of the most important things in life. It's also all* ***the plants and animals****.*
Used words related to ecosystem	Ants, Bees, Work together	Work together	Community, Environment, Plants, Animals, Help each other	Work together, Help each other, Team work, Plants, Animals
Key content in writing	Example: ants and bees Mechanism: work together	Social Interaction →		Example: plants and animals Mechanism: work together, help each other, team work
Development of cognition through writing				

Similar to Michael, the other students' writing exhibited this expanding process, with the exception of Ruby's. These students exhibited more specific ideas about the ecosystem. For example, in his first writing sample, Noah made a list of words including "earth," "plants," "trees," and "animals." After a small group discussion, he presented his initial inference that "the ecosystem has a lot of different things in it" [NB, Noah (H), Day 1]. This inference was expanded through engaging in social interaction. In writing from day 2, he recorded his idea that, "The ecosystem is huge" and explained, "… all those things add on to the ecosystem" [NB, Noah (H), Day 2]. This idea was aligned with his initial inference that "the ecosystem has a lot of different things in it" [NB, Noah (H), Day 1], since it could be argued that "the ecosystem is huge that all those things add on to" [NB, Noah (H), Day 2]. On day 6, Noah wrote that "My knowledge of the ecosystem is (there) are more than one ecosystem. But there a lot of things in them." Similar to Michael, Noah's ideas about ecosystems had not changed much, but it is noticeable that he also used resources that emerged in and were shared through social interactions. These influenced, to some degree, the expansion of his inference, but it is hard to argue that his reasoning was developed during this phase. With this in mind, the data analysis pinpointed how in this phase, the students' undeveloped reasoning emerged in their writing samples. This undeveloped reasoning exhibited their fuzzy understanding, but the expansion or elaboration of their initial inferences was also identified. This expansion was largely influenced by students' engagement in social interactions such as group and class discussion that served to increase their resources.

In summary, students' writing from days 1 to 6 exemplified the first phase that illustrated their fuzzy understanding. Fuzzy understanding was understood as their initial inference represented by their limited cognitive and linguistic resources. Therefore, the undeveloped reasoning structures that were identified in their writing indicated that their level of explanatory power was low. Participating in social interaction over time influenced the increases in cognitive and linguistic resources. In applying the concept of Discourse Space, new cognitive and linguistic resources emerged in the space, some increases of resources were observed over time.

This increase of resource affected the expansion of Discourse Space. Table 4-2 provides a summary of this phase.

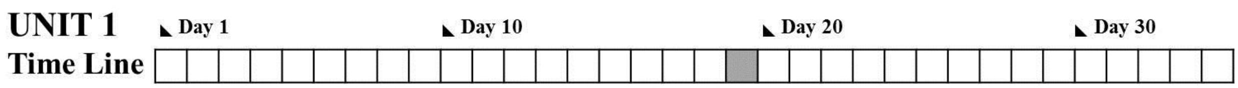
Table 4-2 Summary of Phase 1

<u>Phase 1: Fuzzy Understanding</u>

Example: *When I closed my eyes the first thing that was in my mind was about Eart [Earth]* and the planets that are around Earth. Like the soloar [solar] system thats [that's] what I was thinking about. The tree gave the boy things, but the boy never gave anything back for exchange. The tree gave him shade to sleep under, braches to swing on, leafs and branches to make a house, and the trunk to make a boat but the boy gave the tree nothing back for exchange. But the tree and boy helped each other live*. [Ruby (L), Notebook (NB), Day1]

1. Complexity of Reasoning	▪ Undeveloped reasoning
2. Level of Scientific Explanation	▪ Low explanatory power : difficult to describe it as scientific explanation
3. Development of Discourse Space	▪ Expansion of horizontal DS
4. General Features that Emerged in Writing	▪ Initial inference (fuzzy understanding) ▪ Increase in use of cognitive and linguistic resources

Phase 2: Seeking alternatives: developing an argument with a single unit of reasoning



- Used Writing Samples on Day 19
- Activities: Design Test, Writing, Group Work, Whole Class Discussion, Teacher Reading (Ecosystems, Pollution), Student Reading Watching Videos (Biodiversity, Garbage, Global warming)

This increase of cognitive and linguistic resources helped students seek alternatives based upon their initial inferences. The process of seeking alternatives accompanied the appearance of a single unit of reasoning in participants' writing samples. This single unit of reasoning embraced a single argument supported by connections between a few ideas, and helped to present what happened by describing, summarizing, or restating the pattern or trend that students observed in data (Yoon & Hand, 2012). Since students' understanding of the topic, writing skill, and cognitive ability varied, the moment at which a single unit of reasoning was identified occurred at different times in each student's writing. However, it was on day 19 that all participants' writing illustrated a single unit of reasoning. In other words, the ideas that emerged in students' writing became more elaborate and often presented a single unit of reasoning after day 6, but most participants' writing samples illustrated their fuzzy understanding through day 18.

By day 19, students had engaged in both private and public negotiation including writing, discussion, group investigation, watching a video about biodiversity, operating a microscope as a tool for group investigation, reading about recycling, and seeking information for group investigation. Students' engagement in these multiple activities influenced the increase of cognitive and linguistic resources that students might be used for their idea development. During this period, the major activity was seen as students' group investigation. In this investigation, group members elaborated the question that they wanted to investigate based upon the shared questions that students brought up at the beginning of the unit. Every day, students spent 20 to 30 minutes observing and discussing their experiments, and they were encouraged to record their observations and discussions. In addition to group activities, Mrs. Shelly prepared a video clip regarding biodiversity and read a book about recycling to help students understand ecosystems. The primary goal of these two activities, as articulated by Mrs. Shelly, was to elaborate students' initial ideas [IC with Mrs. Shelly, day 13].

On day 19, students engaged in two writing activities. The first task was to seek information. Students as a group engaged in reading books or searching the Internet to find information that could be used to support their claims regarding group investigations. They spent approximately 30 minutes seeking information and recording what they found. After this writing activity, Mrs. Shelly showed the students a prompt: "Explain to a second grade student why it is important to keep the environment clean," which was presented on the smart board. There was no discussion to reflect on their previous learning before writing. In other words, students did not have opportunities to engage in public negotiation for sharing their ideas regarding the prompt, or for reflecting on their previous understanding. Students had five minutes for this writing task, and Mrs. Shelly stated that this writing would not be used as an assessment.

The data analysis indicated that the six participants' second writing samples from day 19 showed commonality in that the students used examples of pollution to support their arguments, and those examples were about littering and recycling, which they seen in the video clip. Ideas related to the environment, pollution, and recycling thus seemed derived from previous activities including concept mapping (day 1-3), watching a video clip (day 9) and reading a book about recycling (day 13). From days 1 to 3, students collaboratively built the class concept map at the beginning of the unit (see figure 4-1). In this map, the concept of the environment was used as the connecting concept between the ecosystem as a big idea and recycling as a sub concept of the environment. On day 9, students watched a video clip about biodiversity and listed important concepts. The video clip offered diverse information such as the definition of biodiversity, an explanation of the mechanisms of the ecosystem (interaction and interdependency), and information about pollution, aquatic ecosystems, and recycling. On day 13, Mrs. Shelly read a book about recycling to help students understand the environment.

The primary goal of the writing task on day 19 was to elaborate and review ideas that students had shared and developed about ecosystems, recycling, and the environment. The writing task asked students to reason. For example, Noah wrote down his reasoning as follows:

> It is important to keep it clean because the world will be covered in trash. If the world was covered in trash then we couldn't drive cars. We would also have trouble walking. Stores would also be all trash. Animals would eat it and we would lose animal species. [NB, Noah (H), day 19]

Noah's writing consisted of eight clauses. Table 4-3 shows his texts arranged according to the clauses of his sentences. The first clause served not only as the introduction by restating the prompt, but also included his claim as a result of the reasoning process. In the second clause, he presented his reason that, "the world will be covered in trash." This sentence used the passive voice, so that the word "trash" could be understood as the primary theme of this clause. Throughout his writing, this word played a key role in the connection of ideas to present his reasoning. Other clauses supported his reasoning in a sequence. Clause 2 was repeated in clause 3 as the conditional clause, "if (*clause 2*)." Clause 4 described the situation that would occur if the conditional scenario in clause 3 happened (we couldn't drive cars). It still linked to the word (trash) used for the theme in clause 2. Clause 5 added another situation, "We would also have trouble walking," and it could be understood that this situation would occur because of trash. It would influence the amount of trash in stores (clause 6), and if so, animals would eat it (trash) (clause 7), so that "we would lose animal species" (clause 8). Therefore, Noah's claim was "it is important to keep it clean," which returned to clause 1.

Table 4-3 Noah's Day 19 Writing Sample

Number	Clauses
1	It is important to keep it clean
2	because the world will be covered in trash
3	If the world was covered in trash
4	then we couldn't drive cars
5	We would also have trouble walking
6	Stores would also be all trash
7	Animals would eat it
8	and we would lose animal species

If clause 1 was seen as Noah's claim, clause 2 was his simple type of evidence. Other clauses contained meanings or information to sequentially support his evidence in clause 2. He did not use any data he could manipulate or test, but instead used hypothetical thinking to support his reasoning. In a graphical representation of his reasoning, the structure of reasoning looked like a circle connecting each idea to the first even though his writing did not explicitly present these links. With this in mind, the complexity of reasoning of his writing was identified as a single unit of reasoning. His explanation was related to social scientific issues, rather than to a scientific explanation with respect to natural phenomena. The level of explanation thus seemed low, but it is important that this explanation was beginning to gain more explanatory power than his initial inference. Figure 4-2 provides the graphical representation of the reasoning that emerged in Noah's day 19 writing.

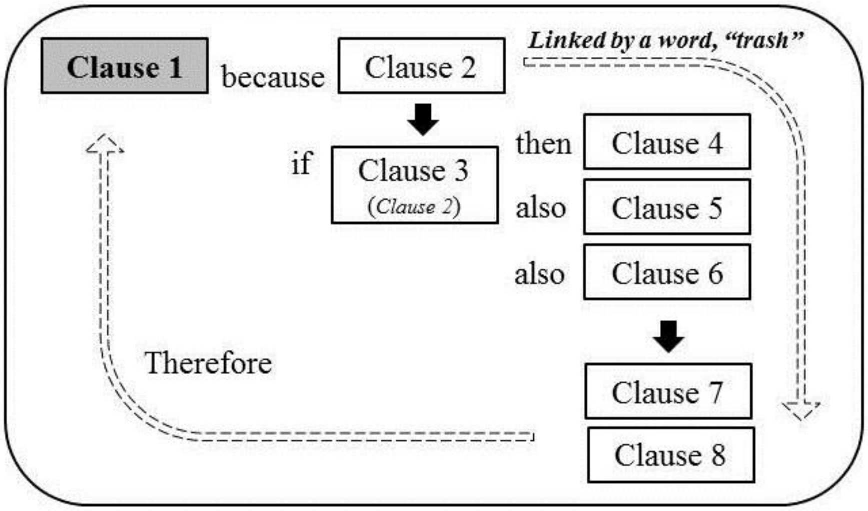


Figure 4-2 Reasoning structure in Noah's day 19 writing

The other five participants' writing samples exhibited similar structures of reasoning and an identical level of scientific explanation. For example, Ivy explained her idea as follows:

> Keeping are [our] environment clean is important because if we didn't keep it clean not many people would enjoy living there. Also living in a dirty environment could be hazardness [hazardous] to kids' health. A dirty environment could also be bad for animals. [NB, Ivy (L), day 19]

Similar to Noah, Ivy explained her reasoning by presenting the relation between "a dirty environment" and living things including "people, kids, and animals." Differing from Noah, she did not use a specific example of a "dirty" environment, but similarly described the harmful influence of such an environment on people and animals. Her complexity of reasoning was identified as a single unit of reasoning, and her level of scientific explanation was also low. Table 4-4 shows her texts arranged according to the clauses of her sentences, and figure 4-3 shows the graphical representation of the reasoning that emerged in Ivy's day 19 writing.

Table 4-4 Ivy's Day 19 Writing Sample

Number	Clauses
1	Keeping are [our] environment clean is important
2	because if we didn't keep it clean
3	not many people would enjoy living there
4	Also living in a dirty environment could be hazardness [hazardous] to kids' health
5	A dirty environment could also be bad for animals

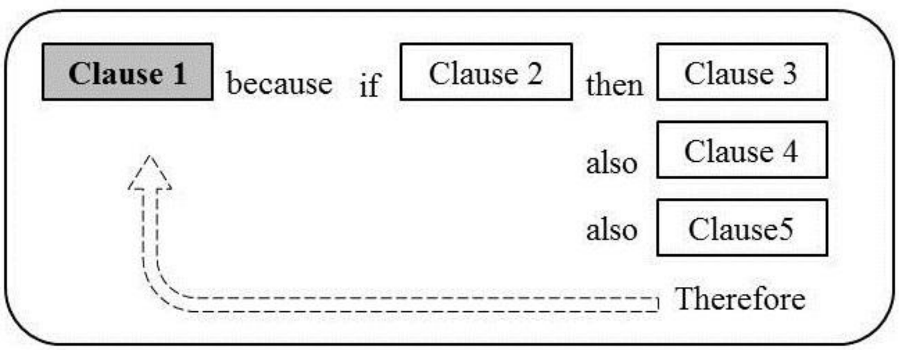


Figure 4-3 Reasoning structure in Ivy's day 19 writing

As another example, Chloe's writing sample showed a similar pattern; however, this text differed from the previous samples in that it contained expressions that considered her audience. The potential audience of this writing task was second grade students who were younger than the student writers. From this viewpoint, Chloe recorded her reasoning as follows:

> You need to recycle and keep the Earth clean because then everywhere you go will have trash, and some animals can think it's food and can kill themselves eating the trash. Also do you want trash everywhere in your yard where you play? Probably no, so if you see trash, get gloves and throw it away even if you didn't litter. Be the better person, and keep the world clean. [NB, Chloe (M), day 19]

Compared to the other writing samples, it could be argued that the explanatory power of Chloe's texts seemed similar to that of the other students, but that her persuasive power seemed higher. Her texts seemed relatively close to the persuasive verbal language style as rhetoric purpose. Asking a question of her potential audience (*do you want trash everywhere in your yard where you play*?), predicting that audience's response (*Probably no*), and persuading the audience based on her reasoning (*so if you see trash, get gloves and throw it away even if you didn't litter. Be the better person, and keep the world clean*) were linked to the verbal language style of her writing. However, in terms of the contents of the texts, there was no large difference between Chloe's and the other students' texts. Her text exhibited the same pattern of a single unit of reasoning and a low level of scientific explanation.

The Beginning of the Development of Discourse Space.

Over time, students started to build up their explanations of natural phenomena. As described earlier, the class had collaboratively constructed a concept map of an ecosystem at the beginning of the unit. Students did not engage in any additional activities through which to further elaborate or revise that map. However, Mrs. Shelly posted the original concept map on the white board located in the back of the classroom (see figure 4-1). In the concept map, students built several links, and the data analysis revealed that their writing on day 19 included several explicit and implicit relations between links. Figure 4-4 schematizes the actual concept map built by students in figure 4-1.

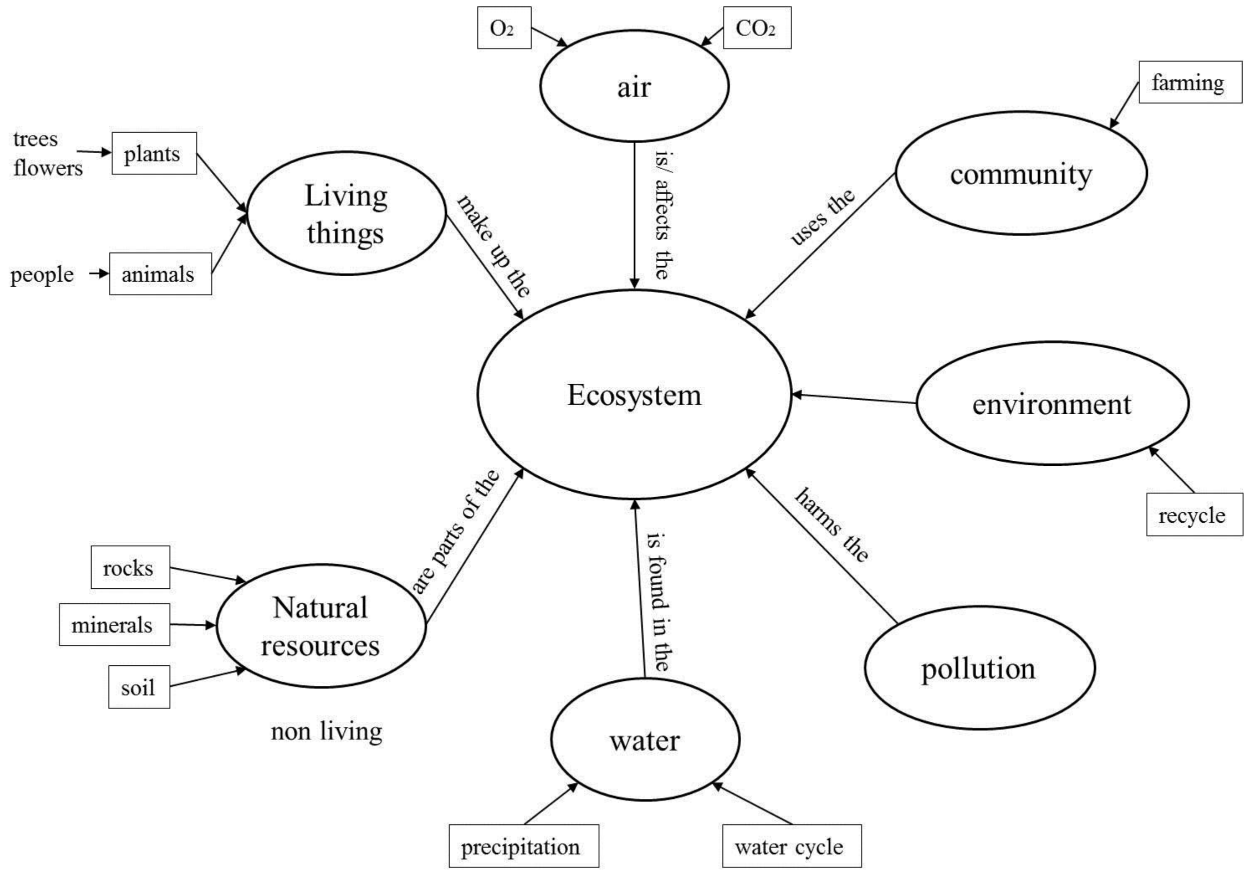


Figure 4-4 A modified class concept map

In Noah's writing on day 19, he used three main concepts from the map: a) living things, b) environment, and c) pollution. This could be linked to the goal of the day 19 writing task since Mrs. Shelly aimed for students to elaborate and review their understanding of pollution, the environment, and its relation to the ecosystem by providing the prompt, "Explain to a second grade student why it is important to keep the environment clean." His understanding of the environment, pollution, and its relationship to the ecosystem including living things could be graphically represented in figure 4-5, drawing from data analysis focusing on the complexity of reasoning.

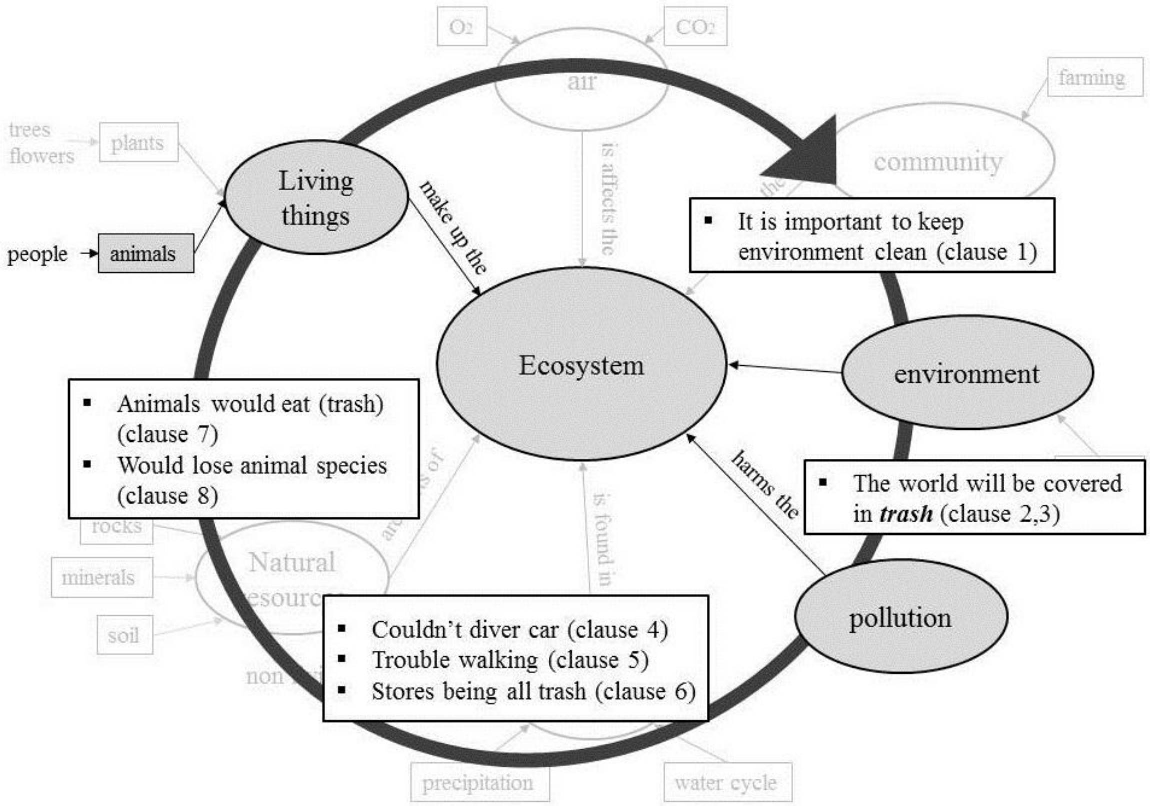


Figure 4-5 Concepts and reasoning that emerged in Noah's day 19 writing

In figure 4-5, the concepts Noah actually used in his writing have been foregrounded, and his writing in the rectangular boxes was added over the modified concept map to illustrate his single unit of reasoning. Although he did not explicitly present the links illustrated in figure 4-5, the data analysis indicated that he developed his reasoning by connecting these concepts or ideas.

It might be hard to parallel Noah's explanation with scientific explanations that were built in the scientific community. However, it could be argued that his explanation was in the process of development. By day 19, he could have employed multiple cognitive and linguistic resources. Some of those resources might have originated from his previous knowledge, and others might have been adopted from shared resources through his engagement in public negotiation. The resources that he used in his day 19 writing were, however, limited. In other words, in the process of cognitive development, newly expanded resources were not identified. Rather, the data analysis indicated that Noah used only a few resources to build his reasoning. As figure 4-5 indicates, he used a narrowed or limited version of ideas that were represented in the concept map. His use of “world” indicated a concept, “environment”; the word “trash” represented the concept of “pollution”; and human activity (“we,” “driving cars,” and “walking to the store”) and animals referred to living things. Although his reasoning contained the interactive and interdependent relationship between living things and the environment as non-living things, as the big idea presented, the resources he used were limited. In other words, he did not explicitly link one idea to another to build his cognition of the big idea. Also, he did not utilize the diverse resources to which he had access. Therefore, only a single unit of reasoning emerged in his writing, so that it could be argued that his reasoning in this phase represented the beginning stage of the development of cognition. Figure 4-6 shows a schematic representation of Noah’s beginning stage of the development of understanding in terms of Discourse Space.

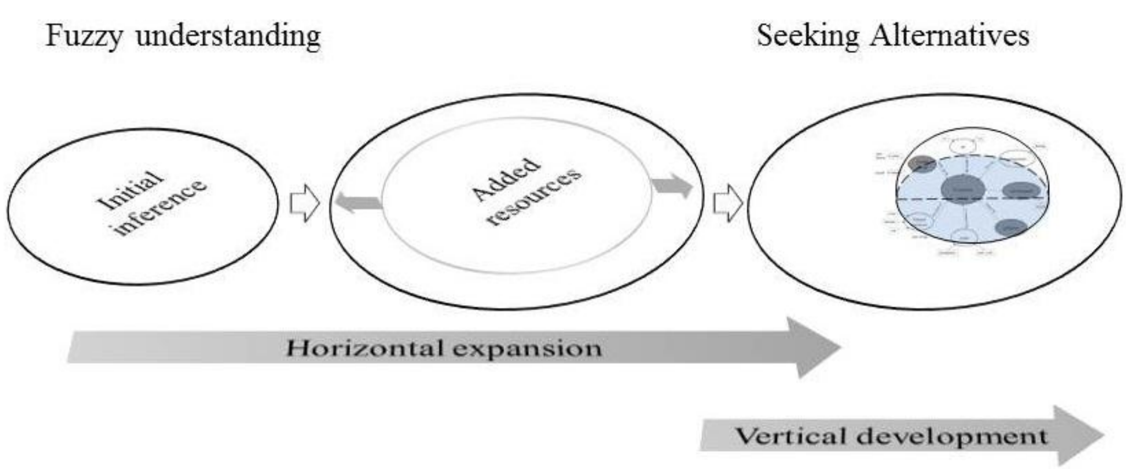


Figure 4-6 The development of written Discourse Space that emerged in Noah’s day 19 writing

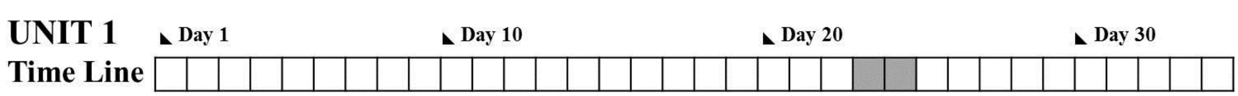
At the beginning of the unit, students generated an initial inference that exhibited their fuzzy understanding. While engaged in social interactions and ongoing reading and writing activities, they started to seek alternatives based on diverse cognitive and linguistic resources that they created and shared to scrutinize their inference and to build up their explanation of natural phenomena. Even though students used limited resources and did not explicitly link concepts in this phase, the data analysis revealed that they started to build their explanations in a way that could be understood as vertically developed discourse. This vertically developed Discourse Space always emerged after the horizontal discourse occurred. According to Bernstein's (1999) concept of horizontal and vertical discourse, the vertically developed discourse indicated that students as participants in discourse started to elaborate, evaluate, and advance ideas based upon resources that they generated and shared. This vertical discourse was to build a coherent story that had a systematically principled structure, or was hierarchically organized.

In summary, during this phase students aimed to seek alternatives to build their own explanations based on their initial inferences. A single unit of reasoning was identified in their texts, but this reasoning was not enough to construct a scientific explanation. However, as observed in Noah's day 19 writing, students started to build their explanation with reasoning. In terms of Discourse Space, the data analysis indicated that some development occurred, but that students used the resources available to them in only a limited fashion. Table 4-5 provides a summary of this phase.

Table 4-5 Summary of Phase 2

Phase 2: Seeking Alternatives	
Example: *It is important to keep it clean because the world will be covered in trash. If the world was covered in trash then we couldn't drive cars. We would also have trouble walking. Stores would also be all trash. Animals would eat it and we would lose animal species*. [NB, Noah (H), day 19]	
1. Complexity of Reasoning	▪ A single unit of reasoning
2. Level of Scientific Explanation	▪ Low explanatory power based on hypothetical thinking
3. Development of Discourse Space	▪ Beginning of development of vertical DS
4. General Features that Emerged in Writing	▪ Building own explanation of topic upon initial inference ▪ Increases in cognitive and linguistic resources used

Phase 3: Towards Comparing Ideas: Appearance of Scientific Reasoning



- Used Writing Samples on Days 23-24
- Activities: Whole Class Discussion, Teacher Reading (Save Energy, Pollution), Watching Videos (Global Warming), Writing, Group Work

This phase was linked to students' attempts to compare multiple ideas to develop their cognition beyond using only a single unit of reasoning. Not all students' writing samples, however, explicitly presented their attempts to compare ideas to build more elaborated explanations. Some students' writing samples still illustrated a fuzzy understanding similar to their initial inferences, and other samples were only possibly linked to their attempts to seek alternatives. Considering pre, present, and post contexts and purposes of writing tasks, the data analysis suggested the development of the students' understanding was moving toward the phase of comparing ideas.

During this phase, students engaged in diverse activities to learn about humans' effects on the ecosystem. The activities included completing crossword puzzles, reading (about the ecosystem, global warming, and pollution), watching videos (about garbage, pollution, and wetlands), writing, and presenting groups' investigations. Mrs. Shelly explained that her intention for reading and watching videos related to pollution and global warming was that she wanted to help students understand how human beings as living things interacted with their environment, and what we as human beings need to do to save or make clean the environments where we live [IC with Mrs. Shelly, day 24]. With this in mind, students engaged in activities during this phase that correlated with Mrs. Shelly's goal.

Students' writing samples from days 23 and 24 have been used to illustrate the phase of comparing ideas. Both writing samples were about global warming. Mrs. Shelly clarified that she wanted the students to explore an issue of global warming by understanding the relation between human causes and the environment that was informed by the big idea of the unit [IC with Mrs. Shelly, day 24]. Students shared, discussed, and explored the topic of global warming in days 23 and 24. On day 23, the concept of global warming was first introduced to the class. On that day, students engaged in several activities including group investigation, teacher reading about pollution, and classroom discussion of pollution. In these activities, global warming was not discussed or mentioned. However, as the last activity of the day, students were given a writing task about global warming. After a discussion of pollution, Mrs. Shelly asked the students to write an answer to the prompt, "Who can tell me what global warming is? Do you know?" [FN, day 23]. A few students briefly shared their own ideas about global warming, and then Mrs. Shelly gave all of the students a sheet to guide the writing task. Figure 4-7 shows the writing task sheet Mrs. Shelly distributed to the class.

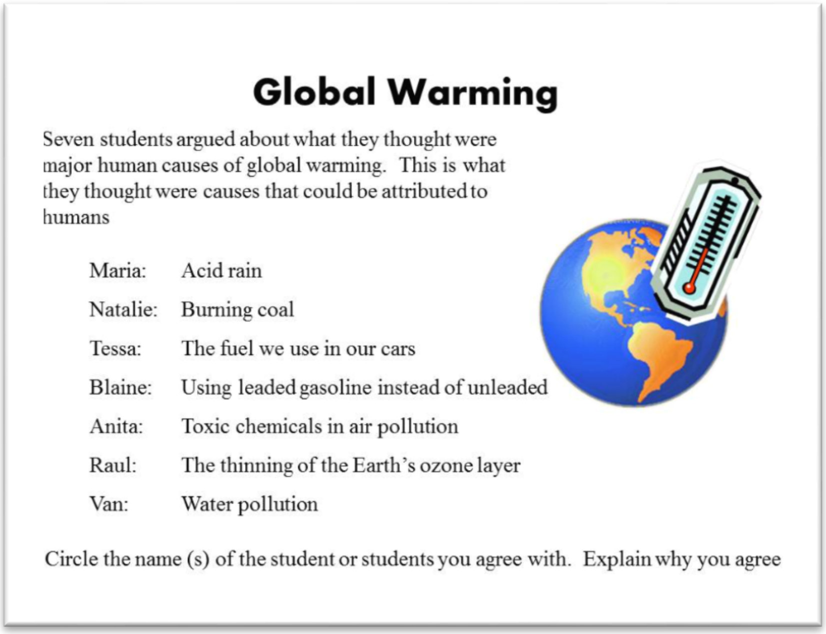


Figure 4-7 The writing prompt about global warming on day 23

Students spent three to five minutes writing. Table 4-6 shows the participants' responses. In their notebooks, the students explained their reasons for why they agreed, but this table only includes a summary of the names of the students with which each participant agreed.

Table 4-6 Participants' Responses to Writing Prompts on Day 23

	Maria	Natalie	Tessa	Blaine	Anita	Raul
Michael		x	x	x	x	x
Noah			x		x	
Chloe			x	x	x	x
Ruby			x	x	x	x
Ivy		x	x		x	x

Note. This writing task was not found in Megan's notebook.

The next day (day 24), the lesson began with sharing individuals' ideas based on their writing from day 23. Students shared their ideas in a whole class discussion for five minutes, and then Mrs. Shelly had the students group up in small groups of three to share their ideas about who they agreed with and to give an explanation of why they agreed with that person. The three-student groups spent five minutes sharing their ideas, and then Mrs. Shelly assigned several individual students to share their group's ideas with the whole class, but there was no further discussion. After sharing, students had two activities: a) class discussion regarding pollution initiated by the teacher reading a book about pollution, and b) observing groups' investigations. After observing groups' investigations, students watched a four-minute video clip about global warming. Then, without discussion, Mrs. Shelly asked them to describe their individual ideas by responding to the writing prompt, "What would you tell a third grader about global warming?"

In the day 23 writing task, the five participants' writing samples illustrated a single unit of reasoning (Megan did not complete this writing task). The students' writing showed similar reasoning flows. Regardless of their use of deduction or induction, the students implicitly considered that pollution causes global warming. Figure 4-8 shows a possible reasoning flow that emerged in most students' writing.

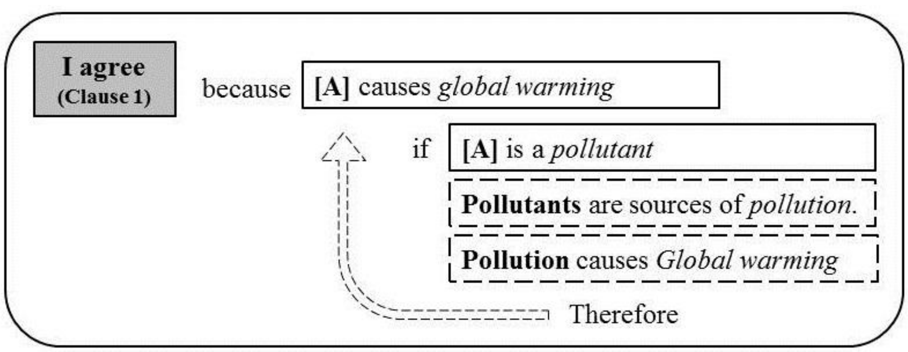


Figure 4-8 A possible reasoning flow related to the day 23 writing task

In this figure, [A] was what each student in the writing prompt thought of as major human causes of global warming. For example, in the prompt, Natalie argued that burning coal was the major human cause. In this case, [A] was burning coal. Since burning coal produced pollutants, Natalie's idea was that the human activity of burning coal caused pollution, resulting in global warming. Differing from other students, Michael added the phenomenon of the thinning Ozone layer. However, his reasoning flow was not very different from the others'. Rather, his explanation could be seen as being more elaborated by adding a piece of scientific information that helped to explain the phenomena. Table 4-7 shows the examined complexity of reasoning and reasoning flows of the students' day 23 writing samples.

Table 4-7 Participants' Day 23 Writing and its Complexity of Reasoning

	Day 23 Writing	Complexity of Reasoning	Reasoning Flow
Michael	I agree because all of those things are released into the air. They all would thin the ozone or heat us with the heat in their pollution.	Single Unit	**[A]** is a *pollutant*. ➡ **Pollution** influences *thinning of the Earth's ozone layer*. ➡ **Thinning ozone layer** causes *global warming*.
Noah	I agree with Tessa because the cars pollute a lot every day. I agree with Anita because air pollution is from cars.	Single Unit	**[A]** is a *pollutant*. ➡ **Pollution** causes *global warming*.
Chloe	I agree with Tessa, Blaine, Anita, and Raul because of their answers. I do think global warming because of the fuel we use in our cars, using leaded gasoline instead of unleaded, toxic chemicals in the air pollution, and because the thinning of the Earth's ozone layer. Because they are all things that can cause bad things.	Single Unit	**[A]** is a *pollutant*. ➡ **Pollution** causes *global warming*. : She described pollution as "bad things."
Ruby	I agree with Tessa, Blaine, and Anita because they are all right. Tessa said "the fuel we use in our cars," that's right. Blaine said "using leaded gasoline instead of unleaded gasoline." Anita said "toxic chemicals in air pollution." I think all of those 3 people are right because they are true. And also I agree with Raul because if we didn't have an ozone layer everyone would pass away, and the reason why is nothing is blocking the sun. Another reason I agree with Tessa is that if we had no gas we couldn't drive anywhere and travel.	Single Unit	**[A]** is a *pollutant*. ➡ **Pollution** causes *global warming*. : Last two sentences of her text were somehow difficult to interpret (…the reason why is nothing is blocking the sun. Another reason I agree with Tessa is that if we had no gas we couldn't drive anywhere and travel). But basically, she followed this reasoning flow.
Ivy	I agree with Tessa and I also agree with Anita because I do agree toxic chemicals pollute the air and global warming. The fuel we use in cars as well pollutes the air and global warming. The other ones I don't agree with but they all pollute the air. I also agree with Raul a little bit cause of the ozone. I agree with Natalie about burning coal. People think we're going to loose [lose] coal, and the world make the hotter.	Single Unit	**[A]** is a *pollutant*. ➡ **Pollution** causes *global warming*. : She seemed to see global warming as an effect of one type of pollution such as air pollution.

Note. The highlighted word is a theme of the sentence, and the underlined italic word is a rhyme, which shows logical connections between words.

By day 24, given the contexts students had engaged in, they potentially had at their disposal more cognitive and linguistic resources. However, the data analysis demonstrated that participants used limited resources for developing their explanations of global warming, and as such it could be argued that their written Discourse Space was not optimized. For example, Mrs. Shelly distributed lots of information related to the ecosystem by reading books, while crossword puzzle activities aimed to provide students with opportunities to learn vocabulary regarding the topic. Students also engaged in group and class discussion based on resources provided by Mrs. Shelly. Furthermore, watching videos helped them obtain more resources that could be used for building their explanations of global warming. However, the data analysis suggested that students used very limited resources and not many attempts were made to synthesize the various cognitive and linguistic resources that appeared in the spoken Discourse Space.

The data analysis of students' day 24 writing samples supported this. The day 24 writing task asked students to describe their individual ideas by responding to the writing prompt "What would you tell a third grader about global warming?" The six participants' texts illustrated three different patterns. The first pattern emerged in Ivy's writing sample. She explained global warming with examples, but presented her personal belief that indicated disagreement with the general ideas of global warming. The second pattern emerged in Michael, Megan and Chloe's writing samples. They briefly defined or described global warming, and then used a persuasive tone to describe how to stop it. The third pattern emerged in Noah and Ruby's writing samples. They focused more on explaining or describing global warming and its mechanisms. Ivy's writing, which exhibited the first pattern, described global warming as follows:

> I would tell a third grader about global warming by saying do you know what the weather is today? If they answered yes, I would say some people in the world think the whole wide world is getting hotter. Well the weather is always changing like some days it's humid, sunny, wet, and other days it's dry, hot, and not moist. That is what I would say to a third grader. Though I don't think it is. [NB, Ivy (L), day 24]

In the second sentence, Ivy described a general view of global warming, "some people in the world think the whole wide world is getting hotter" (clause 5). This description, however, seemed to differ from her own ideas about global warming because she added her view at the end of her text, "Though I don't think it is." This disagreement could be caused by her understanding of global warming. Based on the contexts of her text, she seemed to understand global warming in terms of weather, not climate. In fact, she used the word "weather" and described changes in weather. Therefore, for her, weather continuously changed, and wasn't simply "getting hotter," and this caused her to disagree with her perceived general view of global warming. However, she did not explicitly make a counter-argument against this general view. Some connections between words or ideas were not articulated, and were only implicitly linked to present her idea or claim.

Michael, Megan and Chloe's writing samples illustrated the second pattern. These students projected self as an arguer into their texts to persuade readers (third graders) to help in the fight against global warming. For example, Michael wrote his ideas as follows:

> I would tell a third grader that global warming is a serious problem. No one can clean it up alone. But together, we can stop it. Help out those people. The more people now the more people later. We can't prevent the end of the world. But we can slow it down. [NB, Michael (H), day 24]

Michael described global warming as a serious problem (clause 2). This implied that it negatively influenced community, society, and the world. In this sense, the following clauses demanded potential readers' participation for controlling (slow it down) or even stopping global warming. However, there was no scientific explanation or detailed information related to global warming such as what caused it and how to stop it. Similar to Michael, Chloe focused largely on calling for a potential audience's participation in her texts. Speech-type language was dominantly used, and scientific explanations about natural phenomena were not found by using a single unit of reasoning. Her writing on day 24 is as follows:

> If you see anybody using chemicals, or owning a factory, yell at them and tell them. Do you wanna live longer, or make a lot of money? Are you crazy? You're going to kill the Earth. The Earth is very important without it. WE WOULDN'T BE HERE! Do what's best for the Earth, if it means less jobs then there's less jobs. But we need to take care of our Earth, if that means creating new cars, then that's what we'll do, don't treat the Earth like junk! Raise your hand, if you agree! Let's save the O-ZONE from getting thinner and save the Earth! Make a newspaper, make a group, make a website, do anything! Do you part. I'm Chloe and I approve this message. [NB, Chloe (M), day 24]

Megan's writing sample also exhibited a similar pattern, but her text provided a bit of explanation to describe the mechanisms of global warming. Although her description needed to be more sophisticated (in a manner similar to Michael's), she suggested ways to stop global warming in detail: a) using solar panels for energy, b) recycling, c) water wheels, and d) windmills. Furthermore, she used information found in the day 23 writing task, "not burning gas or coals." Considering that she used resources in her text, Megan thus utilized more cognitive and linguistic resources than Michael and Chloe, although she used the same complexity of reasoning. Following is Megan's text from day 24.

> I would tell a third grader global warming can kill things if it gets warm enough. Global warming is horrible and we can stop it by using solar panels for energy. We can also stop it by recycling. I would tell a third grader heats ice up and warms earth up. It hurt living things. We can stop by recycling and using solar panels, water wheels, and windmills. We can also stop global warming by not burning gas or coals. [NB, Megan (M), day 24]

The third pattern emerged in Ruby and Noah's writing samples. Both students focused more on explaining the phenomenon of global warming and its effects. Ruby's brief text concisely described why global warming is harmful to humans. She wrote:

> This is what I would tell a 3^{rd} grader about global warming is global warming is bad for the Earth because pollution is just like littering and pollution is a part of global warming. Global warming is bad. [NB, Ruby (L), day 24]

Figure 4-9 illustrates Ruby's reasoning flow. She presented her ideas about why global warming was considered "bad," and her writing showed her unsophisticated understanding of the concept by revealing her misunderstanding of the relationship between pollution and global warming. Although she used some words such as "pollution" and "littering" that students had previously shared and discussed to explore the concept of pollution, the cognitive and linguistic resources Ruby used in this writing task were limited and were not utilized for developing a scientifically plausible explanation of global warming.

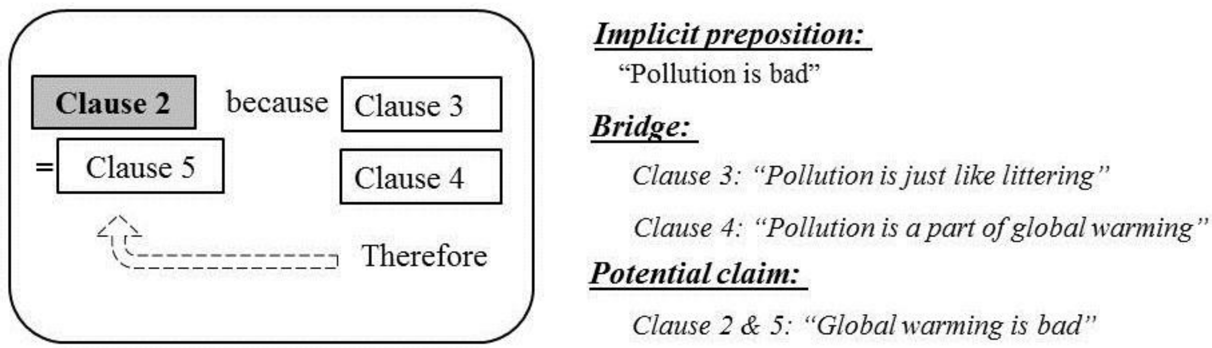


Figure 4-9 A graphical representation of Ruby's reasoning flow

Noah's writing, on the other hand, demonstrated a slightly different approach to describing global warming. His writing focused on the description of a process of global warming caused by human-produced gases. He wrote:

> Global warming is the atmosphere getting hotter and hotter. It is getting hotter because of the Ozone layer thining [thinning]. The Ozone layer is thining [thinning] because of the gases we use. Soon the Earth will have too much sun rays. If there too much sun rays, we could melt and so would kill things. [NB, Noah (H), day 24]

In his text, Noah sequentially described the process of global warming. Clause 1 defined global warming. Clauses 2 and 3 provided a reason for global warming (*thinning ozone layer*).

Clause 4 then supplied a reason for the thinning ozone layer (*the gases we use*). Clause 5 delivered his prediction of what would happen if the ozone layer became thin (too much sun rays). Clauses 6 and 7 provided the hypothetical results of his prediction (*melt and kill*). All of his ideas were sequentially linked to describe the mechanism of global warming and its effects.

The complexity of reasoning in Noah's text was identified as a *developing chain of reasoning*. Though it could not yet be called *a chain of reasoning*, it was nevertheless interpreted as the more developed form of *a single unit of reasoning*. His definition of global warming (clause 1), mechanism (clauses 2 to 5), and its effects (clauses 6 & 7) were logically connected. In his text, he did not present his claim regarding global warming. However, his argument was implicitly presented in clause 7. He might therefore have claimed that we need to stop global warming due to the reasons he provided in his text. His writing could have been expanded if he had added the ways to protect the community, society, or the world from global warming, but this expansion did not actually appear. In this sense, although his text could not be seen as the completed form of *a chain of reasoning*, it could be argued that his reasoning was somewhere between *a single unit of reasoning* and *a chain of reasoning*. Therefore, I call his reasoning structure that emerged in this text the *developing chain of reasoning*.

However, Noah's understanding of global warming was scientifically unacceptable. According to Boyes and Stanisstreet (1992) and Francis, Boyes, Qualter, and Stanisstreet (1992), elementary school students confused the causes of global warming, ozone layer depletion, and atmospheric lead pollution by leaded gasoline. In Noah's reasoning, he explained global warming as a result of ozone layer depletion. Scientists, however, believe that global warming leads to a weaker ozone layer. If the atmospheric temperature rises due to global warming, the natural repairing of the ozone becomes slower because the stratosphere where the ozone layer is found will get relatively colder. Therefore, ozone layer depletion cannot be seen as the direct cause of global warming. However, during this unit, Mrs. Shelly did not explore this issue further since she described her intentions of reading and watching videos related to pollution and global warming as being to help students understand how human beings as living things interacted with their environment, and what we as human beings need to do to save or make clean the environments where we live [IC with Mrs. Shelly, day 24]. In this context, students did not engage in other activities to further explore the concept of global warming.

Elaborated, but isolated development of Discourse Space.

The major goal of this phase was seen as comparing ideas that students had brought, shared, and discussed while engaging in private and public negotiation. During this phase, students could obtain more cognitive and linguistic resources, helping to further develop their cognition regarding the big idea of the unit. In addition, students had more physical time and opportunities to evaluate multiple ideas and resources to build a better understanding of the topic. Since Mrs. Shelly was interested in humans' effects on the ecosystem, the students engaged in activities that focused on the interactive and interdependent relationship between humans as living things and the environment as a non-living thing. In this sense, global warming was discussed and explored within the unit on the ecosystem, so that it was not seen as a separate topic from the big idea of the unit.

By day 24, the students had engaged in multiple activities regarding the ecosystem, biodiversity, pollution, recycling, and garbage. Moreover, they had conducted group investigations based on student-generated investigating questions. Therefore, they had diverse resources that they could use to build up their cognition of global warming, and comparing ideas seemed to be necessary. However, the understanding of global warming that emerged in most students' texts was not fully elaborated. It might be difficult for fifth grade students to acquire a scientific understanding of global warming. The difficulty of the topic itself might have influenced the students' writings on days 23 and 24. Despite the difficulty of understanding global warming, however, students created their explanations, arguments or claims even though most did not explicitly link global warming with other concepts they had learned, and Mrs. Shelly also did not encourage them to integrate multiple ideas.

For example, Noah's day 24 writing illustrated his understanding of global warming as discussed earlier. The understanding that emerged in his text seemed relatively more sophisticated than that of the other students. He focused on the mechanism of global warming and its effects. In his writing sample, connections of multiple ideas were revealed. Those ideas could be linked to concepts such as air, the environment, and pollution in the class concept map students created at the beginning of the unit. Figure 4-10 shows Noah's reasoning flow on the basis of the class concept map.

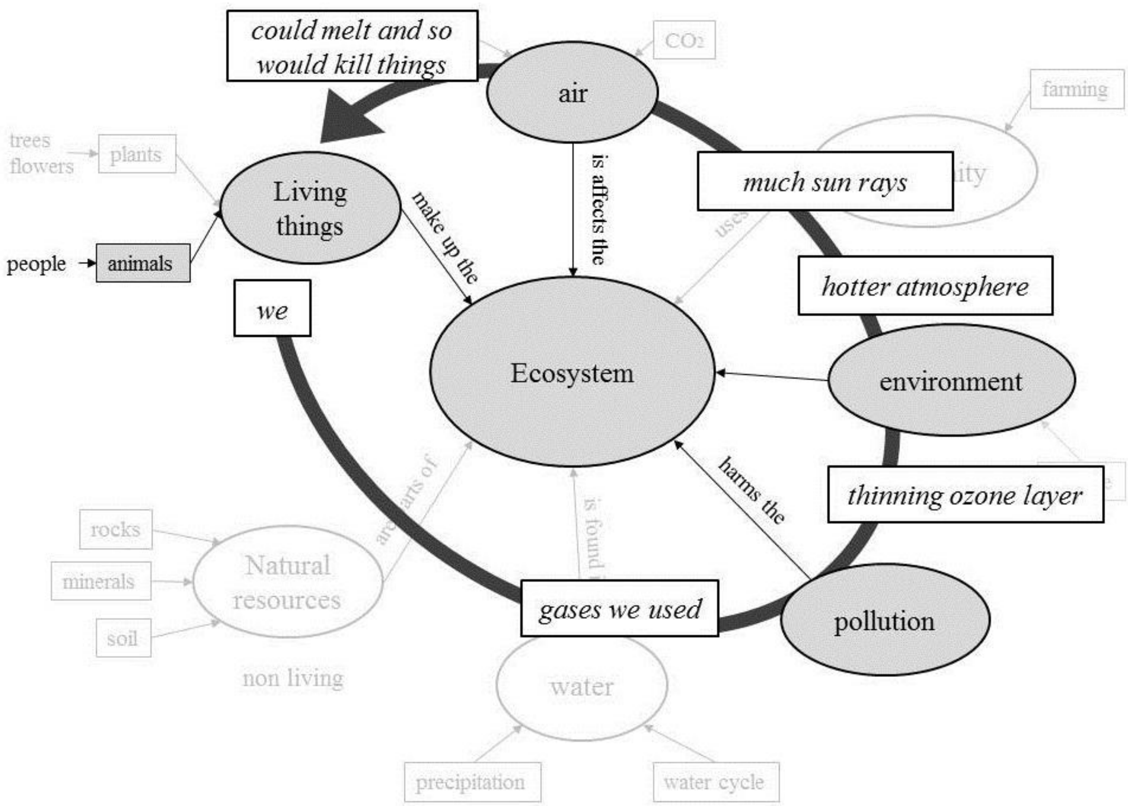


Figure 4-10 Noah's reasoning flow on global warming on day 24

In figure 4-10, the concepts Noah described in his text have been foregrounded, and excerpts from his writing sample were added to show his reasoning flow. Compared to figure 4-

5, his reasoning was more sophisticated, and its focus changed from a relatively contextualized view (what we as living things would suffer, for example, difficulty driving our cars due to the trash) to a more decontextualized view (scientific description regarding the mechanism of global warming). However, the cognitive and linguistic resources he used in this text were limited, and did not link to the other concepts he had learned. This meant that he might have been able to expand his reasoning by comparing ideas he shared, discussed, and developed throughout lessons. Although his reasoning seemed more sophisticated than the reasoning that emerged in his previous texts, the development of his cognition was therefore viewed as an isolated development, rather than the interconnected development that could lead to generating scientifically plausible explanations.

In summary, there was no large difference in this phrase from the previous phase. However, in terms of the level of reasoning, explanatory power, and development of Discourse Space, students' texts exhibited a further-elaborated cognition. Although most texts presented their *single unit of reasoning*, some writing exhibited a *developing chain of reasoning*. A few writing samples still illustrated fuzzy understanding, but most revealed the inclusion of the students' own explanations beyond their initial inferences. The explanations students built went beyond simple describing, restating, or summarizing ideas, so that their explanations now focused more on presenting how a phenomenon happened. However, similar to the previous phase, only some areas or parts of Discourse Space were utilized to develop students' understanding even though they had more cognitive, linguistic, and even physical resources. Table 4-8 summarizes the findings of this phase. The schematic representation in table 4-8 illustrates the expanding and elaborating Discourse Space that occurred in this phase.

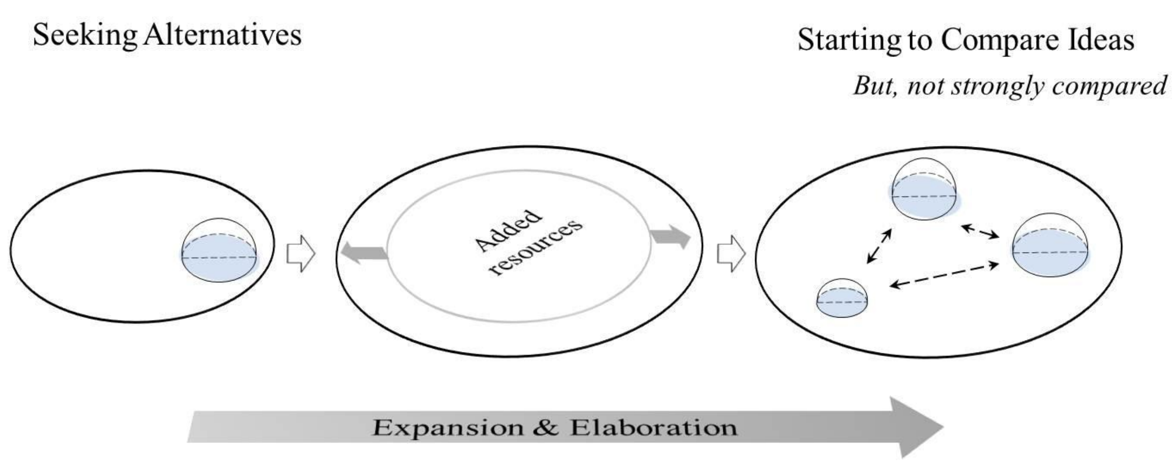
Table 4-8 Summary of Phase 3

<u>Phase 3: Starting to Compare Ideas</u>

Example: Global warming is the atmosphere getting hotter and hotter. It is getting hotter because of the Ozone layer thining [thinning]. The Ozone layer is thining [thinning] because of the gases we use. Soon the Earth will have too much sun rays. If there too much sun rays, we could melt and so would kill things. [NB, Noah (H), day 24]

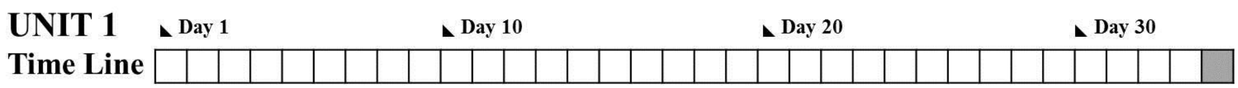
1. Complexity of Reasoning	▪ A single unit of reasoning + Developing chain of reasoning
2. Level of Scientific Explanation	▪ Middle level of explanatory power
3. Development of Discourse Space	▪ Isolated development of vertical DS
4. General Features that Emerged in Writing	▪ Starting to compare multiple ideas to elaborate own explanation of topic ▪ Increases in use of cognitive and linguistic resources

<u>Schematic representation of Phase 3</u>



Phase 4: Comparing and Consolidating Ideas: Having Own

Explanation of the Ecosystem



- Used Writing Samples on Days 34
- Activities: Writing, Group Work, Whole Class Discussion, Teacher Reading (Pollution), Watching Videos (Wetland, Pollution)

During this phase, students aimed to compare and consolidate ideas. They engaged in small group and whole class discussion, group presentations, teacher reading about pollution, watching a video about wetlands, and writing. Students' writing samples from day 34 exemplified the features of this phase. The day 34 writing was a summary writing, and a formal writing task. Mrs. Shelly asked students to write a letter to "explain to readers information (they) talked about during the ecosystem unit" [FN, day 34]. She verbally guided the contents students might consider including in their letters: a) big ideas of the unit, b) definition of ecosystem, c) why living and non-living things interact depending upon one another, d) why ecosystems change, e) what happens if they change, f) what people can do to help the environment, g) what can be learned from the groups' investigation, and h) what you learned during the experiment to improve your future experiments. Then, she gave the students a short instruction to write about their ideas in the form of a letter. This writing was assessed by Mrs. Shelly based largely on students' mechanical writing skills. She informed the researcher that the assessment of "Excellent" for this writing task would indicate an interesting letter including numerous pieces of information from the ecosystem unit, and including all of the areas she had directed students to consider [IC with Mrs. Shelly, day 34].

For this writing task, students spent fifteen to twenty minutes writing their letters. The six participants wrote two- to three-page letters. In general, the students' texts consisted of four parts: a) their explanation of the ecosystem in general, b) a discussion of the changes in the ecosystem, c) the ways to protect the ecosystem, and d) reflection on group investigation. The first part corresponded to Mrs. Shelly's first, second and third guided contents. Students' descriptions of the ecosystem varied; however, they commonly stated that living things and non-living things together formed an ecosystem and interacted and depended upon one another, which could be seen as a big idea of the unit. Compared to their initial inferences regarding the ecosystem that students produced on day 1, these descriptions seemed more articulated and elaborated. Table 4-9 compares writing samples from day 1 (the first day of the unit) and day 34 (the last day of the unit) that illustrate students' ideas about ecosystems in general. In their inferences revealed in day 1writing, most students only used an example of living or non-living things to describe ecosystems. However, in their day 34 writing samples, most students' writing stated that both living and non-living things formed an ecosystem, and added some feature(s) of ecosystems.

For example, following is the first paragraph of Megan's writing from day 34:

> The ecosystem is built up of living and non-living things. You would find anything from moss and algea [algae] to bears, whales, and humans in the ecosystem. In a certain ecosystem whales and water are the largest things, but water doesn't live. In every type of ecosystem it all has a hugest thing and a tiniest thing even if it's living or not. Every ecosystem takes part of earth for its home. If humans or trash or some harm hurts it little by little, the earth couldn't exist as a human area any more. [NB, Megan (M), day 34]

Megan clearly states that ecosystems consist of both living and non-living things in clause 1; describes examples of living things (clause 2); articulates a variety of size of living and non-living things (clauses 3 & 4) and the co-existence of living and non-living things (clauses 5 & 6); and explains the features of interactive and interdependent relationships (clauses 7, 8 & 9). Compared to her initial inference, "Ecosystem is like the whole entire earth or environment. Plants are important to the plant [planet] other than oil and gas" [NB, Megan, day 1], it could be argued that her understanding of ecosystems had developed over time. In terms of reasoning complexity, the shift from undeveloped reasoning in her initial inference to a single unit of reasoning in her day 34 writing was observed. However, both writing samples showed a low level of explanatory power.

Then, Megan's general description was elaborated by describing her view of the changes in the ecosystem and how it could be protected. For instance, she described these issues in the second and third paragraphs of her writing. Followings are those paragraphs:

> People can protect ecosystems by picking up trash or recycling. For a water ecosystem you could pick up trash, so animals don't eat yours [your] trash and it dies. For a forest ecosystem, you shouldn't kill animals you don't need to. For plain ecosystems, you shouldn't bring an alien species that could threaten another. Over all people should be causious [cautious] about what they do in the ecosystem.
>
> If a water ecosystem gets attacked, fisherman might be setting traps and species that get in the traps by accident, may be killed. When this happens, there is no way for the fish or dolphin type animal to get out and try to wriggle free. If a rabbit family or species a bear eats gets wiped out, the bear might starve. If plants were removed from the forest, bears, rabbits, squirls [squirrels], deer, and birds might go hungry. If you take something out of an ecosystem the whole chain might start falling. [NB, Megan (M), day 34]

Megan constructed different paragraphs based on the contents of her writing. In the second paragraph (the first paragraph in the example above), she first described how to protect ecosystems, and then followed that by discussing changes in the ecosystems in the next paragraph. Regarding the ways to protect ecosystems, she provided examples of three different ecosystems: a) water, b) forest, and c) plains. In terms of protection, she described "picking up trash" or "recycling" for a water ecosystem, "not killing animals" for a forest ecosystem, and "not bring an alien species" for a plains ecosystem. In the last two clauses, she pinpointed her awareness of people, saying that "all people should be causious [cautious] about what they do in the ecosystem." Although she did not scientifically elaborate the means of protection, as a fifth grader she nicely wrote about the importance of recycling and not littering (clause 3: animal eat and die) and the negative effect of alien species (clause 8: (it) could threaten another).

Table 4-9 Students' General Ideas about the Ecosystem that Emerged in Texts Produced in Day 1 and Day 34 Writing Samples

	Writing in day 1	A part of writing in day 34
Michael	I thought of ants. They work together. Bees, too. I thought that you shouldn't just take things.	We have learned about how animals, plants, and non-living things are all in an ecosystem.
Noah	Earth, Plants, Trees, Animals	We learned about ecosystem. An ecosystem is an area with living and non-living things in it. All ecosystems have non-living and living things. Ecosystems can be everywhere. There a [are] lot of them.
Megan	Ecosystem is like the whole entire earth or environment. Plants are important to the plant [planet] other than oil and gas.	The ecosystem is built up of living and non-living things. You would find anything from moss and algea algae to bears, whales, and humans in the ecosystem. In a certain ecosystem whales and water are the largest things, but water doesn't live. In every type of ecosystem it all has a hugest thing and a tiniest thing even if it's living or not.
Chloe	The world, How it works with living creatures interacts with it. trees, animals, humans, air, H2O, oxygen, carbon diaoxide, sea creatures, lakes, rivers, Gulf of Mexico, crops, forests, jungles, timber, wild animals, woods, caves, life cycle, sun, clouds, fluffy, clouds, transportation	An ecosystem is a environment in which plants, animals, humans, insects, and other surroundings all live in an area or place. Some common ecosystems are desserts [desert], timbers, rivers, oceans, lakes, and more. Ecosystems are everywhere.
Ruby	When I closed my eyes the first thing that was in my mind was about Eart and the planets that are around Earth. Like the soloar system thats what I was thinking about.	We learned about "Living things interact with and depend upon one another and their environment."
Ivy	Different kinds of systems, Eco	The stuff found in an ecosystem are… plants, animals. Those are living things. In the ecosystem there are also non-living things. In the ecosystem you need to work together like ants and bees. They work together so they can protect one another and not get hurt.

Note. Students' original writing included several grammatical errors. The researcher did not change the errors.

In terms of the complexity of reasoning illustrated in Megan's texts, a *developing chain of reasoning* was identified in the first paragraph of this example. Her reasoning consisted of her proposition (clause 1), evidence presented by examples (clauses 2 to 6), and claim (clauses 7 & 8). The examples used as evidence contained some descriptions of how people could protect ecosystems, and why this protection was needed. For example, she suggested "recycling" and "not littering" because if these things did not happen, animals would die if they ate trash because they thought it was food. This reasoning flow exhibited her cognition of pollution, recycling, and the protection of ecosystems. In other words, her knowledge about pollution, recycling, and protection of ecosystems was compared and interconnected and started to build up a chain-shaped reasoning. However, in her texts, this connection was not explicitly made, and was barely expanded.

The level of explanation that Megan made through her reasoning could therefore not be seen as high, which would parallel a scientific explanation in a conventional manner. Although she described what happened and partially how it happened, it would be difficult to argue that her texts address unobservable/theoretical components tangentially. Thus, the level of scientific explanation in her texts was identified as somewhere between low and middle (*the lower middle*).

In the third paragraph (the second paragraph in the example above), Megan's text presented her reasoning regarding the changes in ecosystems. Using diverse scenarios, she explained the interdependency of ecosystems. Her paragraph consisted of eleven clauses including four parts. The first part (clauses 1 to 5) described the case "if a water ecosystem gets attacked"; the second part (clauses 6 and 7) described the case "if a rabbit family or species a bear eats gets wiped out"; the third part (clauses 8 and 9) described the case "if plants were removed from the forest"; and the fourth part (clauses 10 and 11), as her claim, described the case "if you take something out of an ecosystem." Table 4-10 shows her text arranged according to the clauses of her sentences.

Table 4-10 The Third Paragraph of Megan's Day 34 Writing Sample

Number	Clauses
1	If a water ecosystem gets attacked,
2	fisherman might be setting traps
3	(and) species that get in the traps by accident, may be killed.
4	When this happens,
5	there is no way for the fish or dolphin type animal to get out and try to wriggle free.
6	If a rabbit family or species a bear eats gets wiped out,
7	the bear might starve.
8	If plants were removed from the forest,
9	bears, rabbits, squirls [squirrels], deer, and birds might go hungry.
10	If you take something out of an ecosystem
11	the whole chain might start falling.

In terms of the complexity of reasoning, Megan's text was identified as *a single unit of reasoning*. It might be argued that the structure to connect each scenario looked like a chain. However, the concept discussed in this paragraph was only changes in ecosystems, so that the scenarios served as examples to support her claim in clauses 10 and 11. In this sense, her reasoning was used to present what happened, which could be seen as a low level of explanatory power.

In the final paragraph of her day 34 writing, Megan reflected on her engagement in group investigation. Her reflection consisted of three parts: a) a brief description of group investigation, b) some suggestions for future investigation, and c) closing sentences to wrap up the genre of the letter. Following is the fourth paragraph of her day 34 writing:

> What I learned from my experiment was that seeds may grow faster in rocks than dirt, sand, and water. From my experiment rocks grew fastest with 3 sprouts. Water came in second with 2 sprouts. Sand came in 3rd with 1 sprout and dirt came in last with 0 sprouts we could see. If I could change a thing, I would have brought in sunflower seeds right off the plant and sunflower seeds out of the store. I would have been

> exact on how many eyedroppers we put in our cup every day. I would have gotten more than one source if though of how or what to google. If I could go back to making the experiment, I would have made question different than what it was. Now you know how science went mom. Make sure to check my grades. [NB, Megan (M), day 34]

In the first part, Megan reflected on the results of her group investigation, in which group members tested seeds with different materials (rock, dirt, sand, and water) to see which sprouted fastest. Their results were somehow different from their expectations and books. In group presentation, her group's claims and ways of controlling variables were critiqued [FN, day 32]. Her reflection seemed contextualized, so that readers who did not know about her tests or presentation might have difficulty understanding her explanations. Further, this influenced the structure of Megan's reasoning. In her reflection, it was difficult to identify any reasoning structure, as well as any scientific explanation. This reflection served as a useful resource to further articulate and elaborate her ideas about scientific investigation and the topic in general, however, her reflection itself could not be identified as scientific explanation.

Megan's writing on day 34 originally consisted of these four paragraphs, which have been individually described to this point. Considering her text from day 34 as a whole, the data analysis suggests that it contained *chains of reasoning*. She used multiple resources to present her understanding of and reflections on the ecosystem by comparing and interconnecting them. However, there was no explicit connection between paragraphs. It might be argued that she combined her understanding that was separately developed based upon Mrs. Shelly's instruction. This instruction seemed to help her frame, construct, or organize her understanding. However, it is important to restate that despite the identical guiding information, all students described their understanding of ecosystems differently. With this in mind, the data analysis suggests that students including Megan built their own explanations of the ecosystem by using multiple cognitive and linguistic resources based on their engagement in multiple activities. Figure 4-11 represents the chains of reasoning that emerged in Megan's day 34 writing.

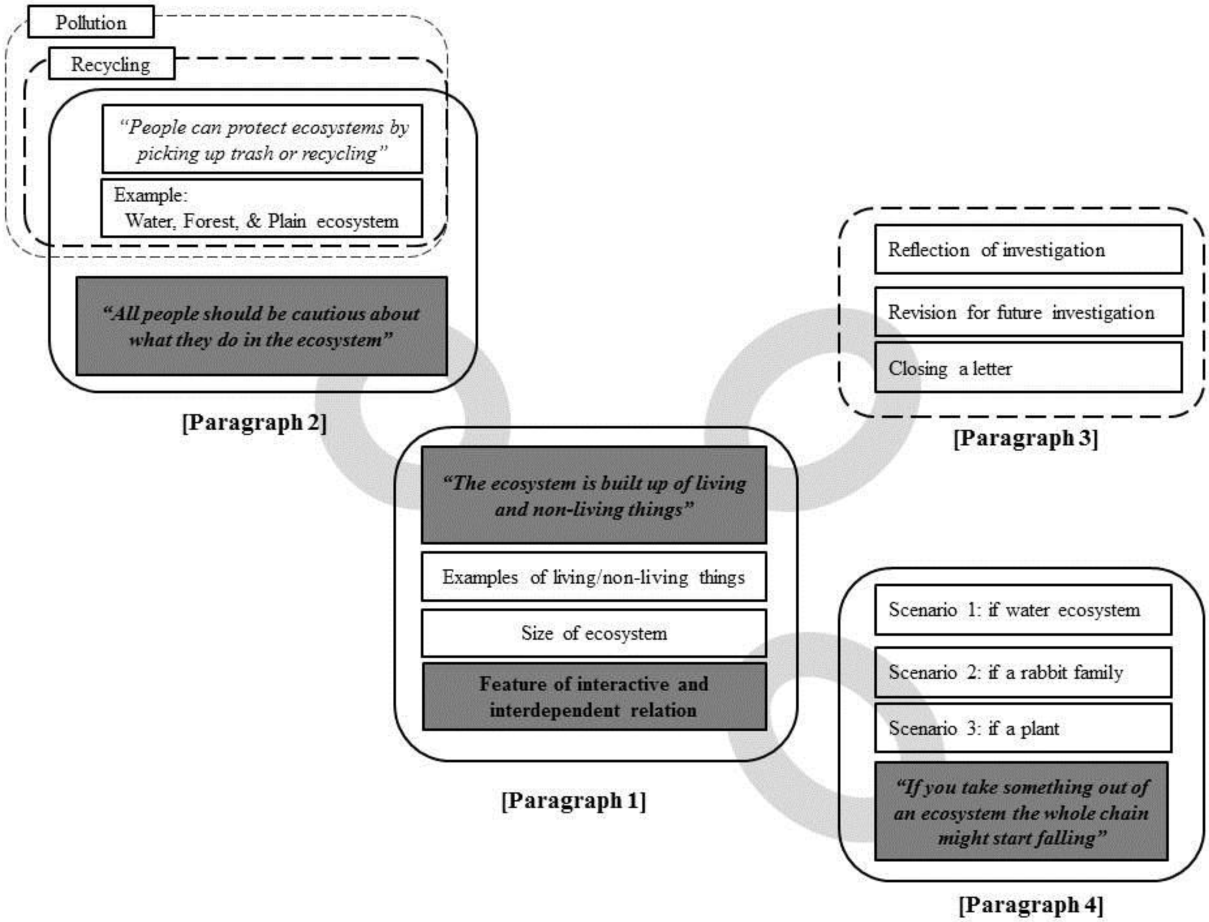


Figure 4-11 Chains of reasoning in Megan's day 34 writing

<u>*Development of Discourse Space, but need more.*</u>

In terms of using resources to build her cognition though writing, most of the cognitive and linguistic resources in Megan's text came from shared resources through social interaction as public negotiation, and from information Mrs. Shelly intentionally provided through reading and video clips. However, this does not mean that Megan just borrowed ideas or meanings that was socially constructed. Importantly, no one used the same resources to describe how to protect the ecosystem just as Megan did. From this point, it could be argued that she chose some resources to describe her understanding, and this process of selecting resources always embraced evaluation. It might be difficult to clearly state in what ways and to what degree of evaluation she engaged for selecting those resources. However, it is worth noting that her engagement in this evaluation process helped to further develop her understanding and helped her to express her ideas in a more sophisticated way. As one of the participants, she had engaged in diverse activities that promoted private and public negotiation. Her text indicated the development of understanding over time, but this development could not be seen as the sudden result of a one-time writing task.

In summary, during this phase, students consolidated their ideas by constructing a coherent story that explained natural phenomena. According to dual-processing accounts, this process promoted their greater engagement in an evaluation process to create quality explanations. Students' texts exhibited their more finely elaborated understanding, and *chains of reasoning* emerged in those texts. This might have been influenced by Mrs. Shelly's guidance, but the data analysis suggests that students utilized cognitive and linguistic resources to build their own explanations. These explanations did not parallel scientific explanations, but they had at least developed over time beyond the initial inferences that had exhibited the students' fuzzy understanding. The level of scientific explanation thus grew to a mid-range. Although the students' texts did not provide any connections between observable events or phenomena and unobservable and theoretical components by using powerful scientific ideas and models, their engagement in group investigation seemed to help them attain a better understanding of ecosystems by presenting how and partially why something happened. Table 4-11 summarizes the features of this phase, and figure 4-12 demonstrates the process of comparison and consolidation.

Table 4-11 Summary of Phase 4

Phase 4: Comparing and Consolidating Ideas

Example:

The ecosystem is built up of living and non-living things. You would find anything from moss and algea [algae] to bears, whales, and humans in the ecosystem. In a certain ecosystem whales and water are the largest things, but water doesn't live. In every type of ecosystem it all has a hugest thing and a tiniest thing even if it's living or not. Every ecosystem takes part of earth for its home. If humans or trash or some harm hurts it little by little, the earth couldn't exist as a human area any more.

People can protect ecosystems by picking up trash or recycling. For a water ecosystem you could pick up trash, so animals don't eat yours trash and it dies. For a forest ecosystem, you shouldn't kill animals you don't need to. For plain ecosystems, you shouldn't bring an alien species that could threaten another. Over all people should be causious [cautious] about what they do in the ecosystem.

If a water ecosystem gets attacked, fisherman might be setting traps and species that get in the traps by accident, may be killed. When this happens, there is no way for the fish or dolphin type animal to get out and try to wriggle free. If a rabbit family or species a bear eats gets wiped out, the bear might starve. If plants were removed from the forest, bears, rabbits, squirls [squirrels], deer, and birds might go hungry. If you take something out of an ecosystem the whole chain might start falling.

What I learned from my experiment was that seeds may grow faster in rocks than dirt, sand, and water. From my experiment rocks grew fastest with 3 sprouts. Water came in second with 2 sprouts. Sand came in 3rd with 1 sprout and dirt came in last with 0 sprouts we could see. If I could change a thing, I would have brought in sunflower seeds right off the plant and sunflower seeds out of the store. I would have been exact on how many eyedroppers we put in our cup every day. I would have gotten more than one source if though of how or what to google. If I could go back to making the experiment, I would have made question different than what it was. Now you know how science went mom. Make sure to check my grades.

[NB, Megan (M), day 34]

1. Complexity of Reasoning	▪ Chains of reasoning
2. Level of Scientific Explanation	▪ Middle level of explanatory power
3. Development of Discourse Space	▪ Not fully synthesizing multiple individually developed DS
4. General Features that Emerged in Writing	▪ Comparing multiple ideas, and consolidating cognition to further elaborate own explanation of topic ▪ Increases in use of cognitive and linguistic resources ▪ Evaluation process was always included

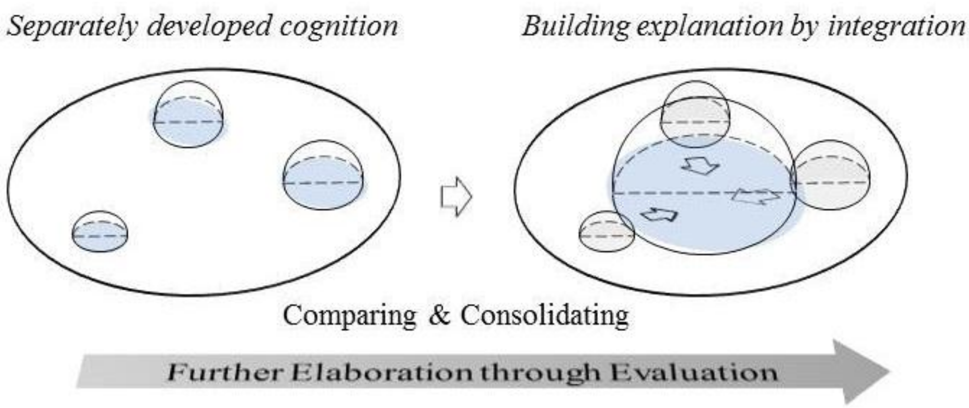


Figure 4-*12 Schematic representation of Phase 4*

Summary of Students' Reasoning Development over Time

In the previous sections, I described six fifth grade students' reasoning development over time. The data analysis indicated that these students' cognition developed from their initial inferences, which had illustrated their fuzzy understanding of ecosystems. In this phase, a reasoning structure and scientifically acceptable explanations were not found in the students' writing. However, their engagement in public negotiation helped to expand the cognitive and linguistic resources the students might use for the development of their understanding. In the second phase, students sought alternatives to explain the concept of the ecosystem. Despite their low explanatory power, the students started to build their own explanations of ecosystems. A single unit of reasoning was identified in students' texts, and their explanations could be understood as the appearance of the vertical development of Discourse Space. In this study, phase 3 marked the intermediate phase that bridged the process of seeking alternatives and the process of comparing ideas. From this point, in phase 3, the students' writing indicated that multiple alternatives including ideas, concepts, and resources were being compared to construct better explanations. The increases in cognitive and linguistic resources, as well as the improved understanding over time of concepts related to ecosystems, influenced the construction of more sophisticated reasoning beyond a single unit of reasoning. However, at this point the students did not yet utilize multiple resources to build their coherent explanations. In phase 4, students fully engaged in the process of comparing ideas and had more opportunities to synthesize their ideas to elaborate their own explanations. In their texts, the chains of reasoning were identified, and their explanatory power was increased. Despite ongoing elaboration, the data analysis suggested that the students' explanations still required more elaboration. Isolated built cognition was not explicitly linked to construct scientifically reasonable explanations, focusing on how and why, beyond describing and restating what happened. Figure 4-13 represents the developing process of Discourse Space based upon these findings. Table 4-12 summarizes scores for the complexity of reasoning and the level of explanation.

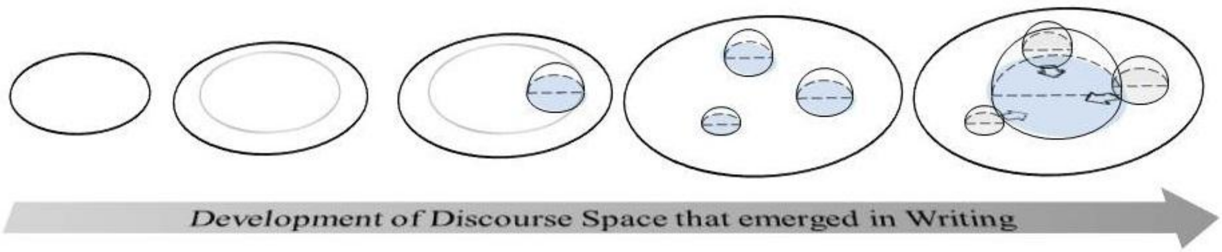


Figure 4-13 The development of written Discourse Space over 9 weeks

Table 4-12 Summary of the Complexity of Reasoning and the Level of Scientific Explanation Students Generated

	The Complexity of Reasoning						The Level of Student-generated Explanation					
Day	Michael	Noah	Chloe	Megan	Ruby	Ivy	Michael	Noah	Chloe	Megan	Ruby	Ivy
Day 1	0	N/A	N/A	0	0	N/A	1	N/A	N/A	1	1	N/A
	0	0	N/A	N/A	0	0	1	1	N/A	N/A	1	1
Day 2	1	0	N/A	0	0	0	1	1	N/A	1	1	1
Day 4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Day 6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	1	0	0	1	0	0	1	1	1	1	1	1
Day 9	0	0	0	0	0	0	1	1	1	1	1	1
Day 13	0	0	0	0	0	0	1	1	1	1	1	1
Day 14	0	0	1	1	0	0	1	1	1	1	1	1
Day 17	0	0	0	0	0	0	1	1	1	1	1	1
Day 18	0	1	0	0	N/A	0	1	1	1	1	N/A	1
Day 19	0	N/A	0	0	0	N/A	1	N/A	1	1	1	N/A
	1	1	1	0	1	1	1	1	1	1	1	1
Day 20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Day 21	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	0	0	0	0	1	1	1	1	1	1
Day 23	1	1	0	0	0	0	1	1	1	1	1	1
	1	1	1	N/A	1	1	1	1	1	N/A	1	1
Day 24	1	2	1	1	1	1	1	1	1	1	1	1
Day 25	1	0	0	0	1	0	1	1	1	1	1	1
Day 26	1	0	0	0	0	0	1	1	1	1	1	1
Day 27	1	1	1	1	N/A	1	1	1	1	1	N/A	1
Day 29	1	2	1	1	1	1	1	2	1	1	1	1
Day 30	1	1	2	N/A	1	1	1	1	2	N/A	1	1
Day 31	1	0	0	1	0	0	1	1	1	1	1	1
Day 33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	0	0	0	0	N/A	0	1	1	1	1	N/A	1
Day 34	3	3	3	3	0	3	3	3	3	3	1	3

Note. The complexity of reasoning (0: undeveloped reasoning, 1: a single unit of reasoning, 2: developing chain of reasoning, 3: chain of reasoning, 4: developing reasoning network, 5: reasoning network, N/A: not available). The level of student-generated explanation (1: low, 2: lower middle, 3: middle, 4: lower high, 5: high, N/A: not available)

Changes in Students' Use of Sources for Making Meaning

Finding 2: Students' use of sources for making meanings through writing changed over time.

This section explores students' use of sources for making meanings. The types of sources that emerged in the texts depended on several factors. Each student's style of using language might affect the type of sources that emerged in his or her texts; conceptual familiarity with the topic of the writing task might influence it; or the student's rhetorical knowledge might impact it. However, this study did not aim to unpack the factors that influenced students' use of sources. Therefore, the important question here was whether a general pattern existed when six fifth grade students developed their understanding over time. In the following sections, I will describe the pattern that occurred in each phase, and then will examine the pattern of students' use of sources when cognitive and linguistic resources in Discourse Space were increased by imported information such as reading and watching videos.

Seeking Patterns in each Phase

Texts used for exploring the complexity of reasoning included six fifth grade students' writing samples produced on days 1, 2, 6 (phase 1), day 19 (phase 2), days 23 and 24 (phase 3), and day 34 (phase 4). The commonality of these writing tasks was that they asked students to produce individual ideas, rather than to record or make a list of what they had observed, heard, or watched. The differences were: a) content, b) date, c) audience, and d) genre. In this section, considering these commonalities and differences, I sought to establish a trend corresponding to the changes of phases.

Phase 1: Increases in Resources and their Representations.

In data analysis, I focused largely on students' use of intuitive sources. According to the analytical framework of this study, meanings represented by intuitive sources should include at least one of three components for making meanings through texts. First, participants in texts should be related to writers. Writers as participants should project themselves into or engage in the process that texts represent. Second, the processes texts describe should be linked to writers' experiences. Process was expressed by verbs in texts. Thus, colloquial language and an active tense might be used more frequently in younger students' texts. Third, the circumstances should indicate the contexts in which writers as participants engaged. Despite this guide, it was difficult to clearly determine some texts. In addition, this study did not aim to explore students' use of personal language and experiences, so that there was limited information about which sources students used in their texts. However, class observation, informal conversation, and other writing samples helped to identify the type of sources students used for making meaning in texts.

For example, in Michael's day 1 writing (see table 4-1), clause 1 was "I thought of ants." This clause clearly indicated that the participant in this text (I) presented a writer (Michael), and he also engaged in the process of making meanings (thought of). Therefore, this clause was identified as an *intuitive source*. Clause 5 (you shouldn't just take things) seemed different from clause 1. However, this clause was also identified as an *intuitive source*. First, the subject of this clause was "you," implying the potential readers that Michael wanted to reach. Therefore, the participant in this text was not the writer himself, but was related to him (speaker-audience relation). In addition, the verb in this clause was "should not take," which indicated the writer's advice or expostulation to his audience. In other words, the writer engaged in the process that his text represented. Consequently, this clause was also identified as an *intuitive source*. With this in mind, the imperative clause, in this study, was identified as using *intuitive sources* for making meaning.

Table 4-13 shows Michael's use of sources for making meaning, as present in day 1 to 6 writing samples that illustrated his fuzzy understanding. In this table, the percentage of intuitive sources gradually decreased. During phase 1, cognitive and linguistic resources increased over time, and the student's engagement in social interactions such as small group and whole class discussion seemed to influence this increase. The data analysis, attempting to explore complexity of reasoning, also revealed the expansion of linguistic resources in the student's texts (see table 4-1). In other words, to elaborate his beginning ideas, Michael was more likely to use the new linguistic resources that were generated and shared through public negotiation. From this point, the data analysis suggests that an expansion of linguistic resources might have influenced Michael's decreasing use of intuitive sources to build up his ideas. In other students' texts, similar patterns were found.

Table 4-13 Sources of Meanings that Emerged in Michael's Writing Samples from Days 1 to 6

	Day 1	Day 1 (2)	Day 2	Day 6
Total # of clauses	10	6	7	6
# of clauses (intuitive)	8	5	5	3
# of clauses (non-intuitive)	2	1	2	3
Percentage of non-intuitive sources	20	17	29	50

Phase 2: The Appearance of Single Reasoning and its Representation.

In phase 2, a single unit of reasoning emerged in students' texts. Their fuzzy understandings represented by inferences were elaborated, but the explanations they generated still indicated low explanatory power, and seemed to depend largely on their hypothetical thinking. The writing sample used for illustrating phase 2 was the writing task on day 19 that asked students to explain to a second grade student why keeping the environment clean was important. In Noah's day 19 writing (see table 4-3), his text consisted of eight clauses. The sources he used in three of these clauses were identified as *intuitive sources* (clauses 4, 5, & 8). In these three clauses, he as a writer projected himself into the role of "we" to present his reasoning. "We," including both you as potential audience and I as a writer, "couldn't drive cars," "would have trouble walking," and "would lose animal species." Because Noah took the role of the participants in these three clauses, the clauses could be identified as *intuitive sources*.

In clauses 2, 3, 6, & 7, it was difficult to see Noah as a participant in the process represented in the meanings of his text. For example, in clause 6 (stores would also be all trash), it might be possible to think of the word "trash" as what "we" littered, and the word "store" as where "we" visited. However, in this study, this was not identified as an *intuitive source*. Although words such as "trash" and "store" seemed contextualized and highly related to his personal experience, in the process of meaning making it was difficult to argue that Noah used intuitive sources to build the meanings illustrated in this clause. However, I identified clause 1 as the clause in which he dominantly used his *intuitive sources*. Clause 1 was a kind of imperative clause, presented as the writer's request. In other words, the participant or person who thought or believed "it is important" was Noah as a writer or speaker, and he implicitly made a request, "keep it clean." As a result of the data analysis, four clauses among eight were identified as *intuitive sources*.

Chloe's day 19 writing sample showed a similar pattern. Table 4-14 displays her text arranged according to the clauses of her sentences. In her text, she made a stronger request to keep the environment clean. Except for clauses 3, 4 & 5, she presented her ideas with an imperative tone. Interestingly, her text was similar to the style of spoken language in that she employed a sort of rhetoric in her writing. She asked questions of potential readers (Do you want trash everywhere in your yard where you play?), and predicted their responses (Probably no). Then, she articulated her requests. This style of writing indicated that, in her text, she as a writer was deeply engaged in the meaning-making process.

Table 4-14 Chloe's Day 19 Writing Arranged According to its Clauses

Number	Clauses
1	You need to recycle and keep the Earth clean
2	because then everywhere you go will have trash, and
3	some animals can think
4	it's food
5	and can kill themselves eating the trash.
6	Also do you want trash everywhere in your yard
7	where you play?
8	Probably no,
9	so if you see trash,
10	get gloves and
11	throw it away
12	even if you didn't litter.
13	Be the better person, and
14	keep the world clean.

In phase 2, students presented their reasoning to explain the importance of keeping the environment clean. The texts that exhibited students' simple reasoning focused more on making a request or offering advice to a potential audience (second grade). To produce this imperative meaning, students tended to project themselves as a speaker into their texts. From this point on, relatively fewer non-intuitive sources were identified in students' texts.

Phase 3: Scientific Explanation and Decreased Use of Intuitive
Sources.

Students' day 23 and 24 writing samples were used to exemplify phase 3. The day 23 writing task asked students to provide reasons for the human causes of global warming, and the day 24 writing task required students to explain global warming to a third grade student. In both tasks, students generated their own reasoning, illustrating more elaborated understanding than their initial inferences. The data analysis on reasoning complexity revealed that students started to compare ideas and to build the lower middle level of explanation. However, the explanation students built was not synthesized, so it appeared to be an isolated development.

This isolated development was represented by students' use of intuitive sources. During phase 3, students used relatively more intuitive sources to represent their reasoning regarding global warming through writing. For example, Ivy produced twelve clauses in her day 24 writing. Table 4-15 shows her text arranged according to the clauses of her sentences. In most clauses, she presented herself as a writer and a speaker to third graders as potential readers and audience (clauses 1, 2, 3, 4, 11 & 12). In clause 5 it was arguable whether an intuitive source was used. However, considering the meanings the text represented, I determined that it as a clause used an intuitive source. Clause 5 was understood as the contents that "I" as a writer wanted to say to a third grader (see clause 4, I would say). From this point, subjects of this clause (some people) were interpreted as people who had different ideas from "me." Although the writer did not project herself explicitly into her text, it could be argued that she was innate within the meanings of the text. As a result, in seven clauses intuitive sources were dominantly used for making meanings.

Table 4-15 Ivy's Day 24 Writing Arranged According to its Clauses

Number	Clauses
1	I would tell a third grader about global warming by saying
2	do you know what the weather is today?
3	If they answered yes,
4	I would say
5	some people in the world think
6	the whole wide world is getting hotter.
7	Well the weather is always changing like
8	some days it's humid, sunny, wet, and
9	other days it's dry, hot, and not moist.
10	That is what
11	I would say to a third grader.
12	Though I don't think it is.

Similar to Ivy, other students used intuitive sources for making meanings regarding global warming. However, Noah's writing sample from day 24 used relatively fewer intuitive sources. While he used intuitive sources to present his ideas in clauses 3 and 6, in the other clauses, scientific sources were used. To describe global warming in general, he defined it (clause 1), explained the cause of global warming (clauses 2, 3, 4 & 5), and predicted its effect on "us" including him as a participant (clause 6). Though clauses 3 and 6 contained intuitive sources, most sources he used in his reasoning were thus identified as scientific. It is worth pinpointing here that scientific sources were utilized to explain Noah's ideas regarding phenomena, which could be seen as student-generated scientific explanation, while other students' reasoning, represented by intuitive sources, focused exclusively on making a request to audiences or readers. This difference might be associated with students' use of sources for making meaning. Since Noah's day 24 writing sample was considered a representative text to illustrate phase 3, it was important to note that at this point students started to distance themselves from their texts, exhibiting their scientific description or explanation, by using fewer intuitive sources. Table 4-16 shows Noah's text arranged according to the clauses of his sentences.

Table 4-16 Noah's Day 24 Writing Arranged According to its Clauses

Number	Clauses
1	Global warming is the atmosphere getting hotter and hotter.
2	It is getting hotter because of the Ozone layer thining [thinning].
3	The Ozone layer is thining [thinning] because of the gases we use.
4	Soon the Earth will have too much sun rays.
5	If there too much sun rays,
6	we could melt and so would kill things.

Phase 4: Difference between Explanation of Nature and Reflection on Experience.

In phase 4, students engaged in a summary writing task. Based on Mrs. Shelly's guidance, they generated two- to three-page texts to show their understanding of ecosystems. In general, students' texts consisted of four parts: a) their explanation of ecosystems in general, b) a description of the changes in ecosystems, c) discussion of the ways to protect ecosystems, and d) reflection on group investigation. However, these four parts were not explicitly and closely connected to one another. The data analysis of students' use of sources suggested that they used different sources for making meanings depending on these parts. Table 4-17 shows the general findings that emerged in six students' day 34 writing samples. Students' use of intuitive sources varied, but over half of the sources used in this writing could be seen as intuitive sources.

Table 4-17 Students' Use of Sources for Making Meanings in Day 34 Writing Samples

	Michael	Noah	Chloe	Megan	Ruby	Ivy
Total # of clauses	25	29	29	39	22	24
# of clauses (intuitive)	11	9	8	17	16	11
# of clauses (non-intuitive)	14	20	21	22	6	13
Percentage of non-intuitive sources	56	69	72	56	27	54

Note. The final number indicates the percentage of non-intuitive sources. This was calculated by a simple equation, [(total # of clauses of the writing) – (# of clauses in which intuitive sources were used)] / (total # of clauses of the writing)*100. (N/A: not available)

When dividing students' texts into four parts based upon their contents, this overall result changed. The biggest change was in the increases in students' use of intuitive sources observed in parts 3 and 4. In parts 1 and 2, students attempted to provide their explanation of ecosystems in general (part 1) and the changes in ecosystems (part 2), while in parts 3 and 4, they seemed to make a request to readers by informing them of the ways to protect the ecosystem (part 3), and to reflect on their experience of engagement in group investigation (part 4). Based on this, it could be argued that parts 1 and 2 exhibited students' explanations of nature, while parts 3 and 4 illustrated their advice to potential readers and their reflections on their experiences. Therefore, each part implicitly demanded from students' different responses through writing, and this influenced their use of sources when representing their ideas. Table 4-18 shows students' use of sources on the basis of these four parts.

Table 4-18 Students' Use of Sources for Making Meanings in Day 34 Writing Samples in Detail

		Michael	Noah	Chloe	Megan	Ruby	Ivy
Part 1	Total # of clauses	2	5	5	11	1	8
	# of clauses (intuitive)	1	1	0	2	0	2
	# of clauses (non-intuitive)	1	4	5	9	1	6
	Percentage of non-intuitive sources	50	80	100	82	100	75
Part 2	Total # of clauses	7	10	12	10	0	5
	# of clauses (intuitive)	0	0	0	1	0	1
	# of clauses (non-intuitive)	7	10	12	9	0	4
	Percentage of non-intuitive sources	100	100	100	90	0	80
Part 3	Total # of clauses	9	8	4	7	0	5
	# of clauses (intuitive)	4	5	3	5	0	5
	# of clauses (non-intuitive)	5	3	1	2	0	0
	Percentage of non-intuitive sources	56	38	25	29	0	0
Part 4	Total # of clauses	7	6	8	11	21	6
	# of clauses (intuitive)	6	3	5	9	16	3
	# of clauses (non-intuitive)	1	3	3	2	5	3
	Percentage of non-intuitive sources	14	50	38	18	24	50

Note. The final number indicates the percentage of non-intuitive sources. It was calculated by a simple equation, [(total # of clauses of the writing) – (# of clauses in which intuitive sources were used)] / (total # of clauses of the writing)*100. (N/A: not available)

Summary

In this section, I explored patterns observed in students' use of sources for making meaning across phases. In phase 1, students dominantly used intuitive sources to build meanings in their texts, but the represented meanings through texts illustrated their fuzzy understanding. However, the students experienced increases in their cognitive and linguistic resources through engagement in social interactions to elaborate their initial inferences. The data analysis suggested that the expansion of linguistic resources influenced students' use of fewer intuitive sources to build up ideas over time. In phase 2, a single unit of reasoning emerged in students' texts. This single reasoning was used to make a request or to offer advice to a potential audience (second grade), and students produced an imperative style in this phase in which they tended to project themselves as speakers into their texts. From this point, relatively fewer non-intuitive sources were identified in their texts. In phase 3, a noticeable difference was identified in students' uses of sources. When students focused more on making a request to audiences or readers, which was observed in phase 2, they tended to use more intuitive sources. However, scientific sources were utilized more when they wanted to explain their ideas regarding phenomena, which could be seen as student-generated scientific explanation. In phase 4, this pattern was distinguished to an even greater degree. In their summary writing, students used sources differently depending on their understanding of the implicit demands of the writing task.

Unique Patterns in Students' Use of Sources

It might be difficult to provide a general pattern by examining limited numbers of participants' writing samples. Moreover, this study did not intend to generalize students' use of sources for making meanings. However, two interesting patterns were identified through the data analysis; this section describes those unique patterns.

Nature of Tasks and Use of Intuitive Sources.

Students engaged in diverse activities throughout the unit on the ecosystem. There were two particular activities that Mrs. Shelly frequently used to provide detailed information that might help students elaborate and develop their ideas about ecosystems. These were teacher reading and watching videos. In teacher reading, Mrs. Shelly read part of a book related to the topic, and facilitated whole class discussion based on the reading's contents. After a short discussion, she continued to read other parts of the book, and again facilitated discussion. After several iterations of this pattern, she asked students to write about their ideas related to the reading by providing a writing prompt. During the unit on the ecosystem, she used this reading and discussion pattern ten times. In watching videos, she prepared video clips and the students watched the clips during lessons. After watching, similar to the reading and discussion pattern, students engaged in writing activities based on a writing prompt Mrs. Shelly had prepared. During the unit, students engaged in the activity of watching a video four times.

The nature of writing tasks varied. However, three patterns were identified based upon the nature of the task. The first pattern was found in students' writing samples that occurred after watching videos on days 9, 21, 26, and 29. These four writing tasks asked students to make a list of important things they thought about after watching videos. Most students tended to record information they saw on the videos. For example, on day 29, Chloe made a list of important things after watching a video regarding wetlands. Table 4-19 shows her text arranged according to the clauses of her sentences.

Table 4-19 Chloe’s Day 29 Writing Arranged According to its Clauses

Number	Clauses
1	Wetlands filter water.
2	Wetlands help prevent floods.
3	People sing songs about wetlands.
4	A pool is not a wetland.
5	Plants slow down the water in wetlands.
6	Wetlands are like sponges.
7	The wetland’s soil has living things everywhere in it.
8	Wetlands are nonrenewable resources,
9	So we should save ’em [them] not kill ’em [them].
10	Wetland’s soil is eather [either] muck or watery.
11	Some people think wetlands are wastelands which is not good.

Except for clauses 9 and 11, intuitive sources were not used in Chloe’s text. The contents or meanings that each clause had were found in the contents of the video clip she watched on day 29. Students’ writing samples on days 9, 21, 26, and 29 occurred after the activity of watching a video. Although the ratio of students’ use of intuitive sources varied, on average only 34 % of sources were identified as intuitive in the six students’ writing samples during these four days.

The second pattern was found in the students’ day 23 writing task. This task occurred after reading a book about pollution. Mrs. Shelly asked the students to define pollution after reading and discussion. Responding to the writing prompt of “What is pollution,” students defined the term with various examples that came from the contents of the book that Mrs. Shelly had read to them. For example, Noah defined pollution as follows:

> Pollution is litter in the ocean. It is also gas and other things that come out of factories. Litter pollution are plastic bottles and nonbiodegradable things. Factory pollution is the smoke that comes out of the smoke towers. [NB, Noah (H), day 23]

Noah did not use any intuitive sources to build his definition of pollution. The examples he used and the technical terminology were imported from the contents of the book. Like Noah, other students' texts contained similar examples to define pollution. On average only 20 % of the sources were identified as intuitive in the six students' day 23 writing samples.

The third pattern was found in writing samples that students produced on days 24, 25, and 27. Differing from the second pattern, writing tasks on these days asked students to describe their ideas. On day 24, after watching a video, students were asked to explain global warming to third graders; on day 25, after reading and discussion, they wrote about how to conserve natural resources; and on day 27, they wrote down their ideas responding to the writing prompt, "How can we do our part to reduce pollution?" It could be argued that these writing tasks asked for students' ideas about possible and positive actions. With this in mind, despite the different topics and contents of the tasks, students' texts focused on making a request to readers to ask for their participation in actions that they as writers or speakers suggested. For instance, in the writing from day 24, some students started to include their reasoning to explain global warming, but most of the students' texts could be linked to advice to potential readers (see findings of phase 3). In general, the data analysis suggested that the nature of these writing tasks was different from those in pattern 1 (recording information) and pattern 2 (defining or explaining phenomena). On average, 83 % of the sources were identified as intuitive in the six students' writing samples from these three days.

In summary, a unique pattern was identified. The pattern was observed in two activities that Mrs. Shelly frequently used to provide new information; these included teacher reading and watching videos. The two activities contributed to expanding the students' cognitive and linguistic resources. When the writing tasks asked students to record information (days 9, 21, 26, & 29), they tended to use fewer intuitive sources to build meanings through writing. Similarly, if the writing task asked students to define phenomena based on shared information, they also used fewer intuitive sources. However, when the writing tasks asked about students' future actions, for example, if they asked about students' ideas regarding conserving natural resources, the students seemed to focus more on making a request for potential readers' participation. With this in mind, the students employed a greater number of intuitive sources.

Gradual Decreases in Intuitive Sources.

Table 4-20 summarizes the overall scores indicating students' use of sources for making meanings through writing. It was difficult to explore the general pattern presented by the numbers in this table. When considering the unique patterns that had formed, the general pattern was dramatically changed. In the previous section, I described the unique pattern of students' use of sources. To explore the general pattern across phases, I paid attention to the first and second patterns. The first pattern indicated that these writing tasks asked students to record information, and the second pattern suggested that the writing task asked students to define phenomena based on shared information. In this sense, the data analysis revealed that students in these writing tasks used sources to represent what they heard, rather than to build their own reasoning. However, I intended to explore any general patterns that might be observed while students developed cognition through writing. Therefore, I purposefully excluded writing samples that exhibited unique patterns (first and second) when investigating the general pattern across phases in this study.

Table 4-20 Percentage of Students' Use of Non-Intuitive Sources in Texts

	Michael	Noah	Chloe	Megan	Ruby	Ivy
Day 1	0	N/A	N/A	100	14	N/A
	17	100	N/A	N/A	0	0
Day 2	29	100	N/A	20	0	0
Day 4	N/A	N/A	N/A	N/A	N/A	N/A
Day 6	N/A	N/A	N/A	N/A	N/A	N/A
	50	100	58	100	33	75
Day 9	42	83	50	44	90	33
Day 13	0	50	0	0	0	14
Day 14	0	25	14	0	25	0
Day 17	17	50	20	0	13	29
Day 18	25	67	0	0	N/A	0
Day 19	50	N/A	0	0	0	N/A
	13	50	21	0	0	60
Day 20	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	N/A	N/A	N/A	N/A
Day 21	N/A	N/A	N/A	N/A	N/A	N/A
	9	43	27	20	11	0
	72	100	63	40	100	46
Day 23	75	100	67	100	71	67
	33	25	33	N/A	0	33
Day 24	11	67	5	10	25	42
Day 25	13	0	20	0	0	0
Day 26	73	50	70	60	40	45
Day 27	10	75	0	17	N/A	0
Day 29	100	86	82	60	100	43
Day 30	50	50	31	N/A	17	0
Day 31	25	0	0	0	0	25
Day 33	N/A	N/A	N/A	N/A	N/A	N/A
	20	0	0	0	N/A	0
Day 34	56	69	72	56	27	54

Note. The number indicates the percentage of non-intuitive sources. It was calculated by a simple equation, [(total # of clauses of the writing) – (# of clauses in which intuitive sources were used)] / (total # of clauses of the writing)*100. (N/A: not available)

The general pattern was found after eliminating samples that exhibited the unique patterns. In general, although the trend of days 1 to 6 was seen as inconsistent with the general trend, and a somewhat fluctuating trend was observed, the general pattern indicated that students gradually used fewer intuitive sources for making meanings through writing. Figure 4-14 graphically illustrates this pattern. Numbers on this graph indicate the percentage of students' use of non-intuitive sources.

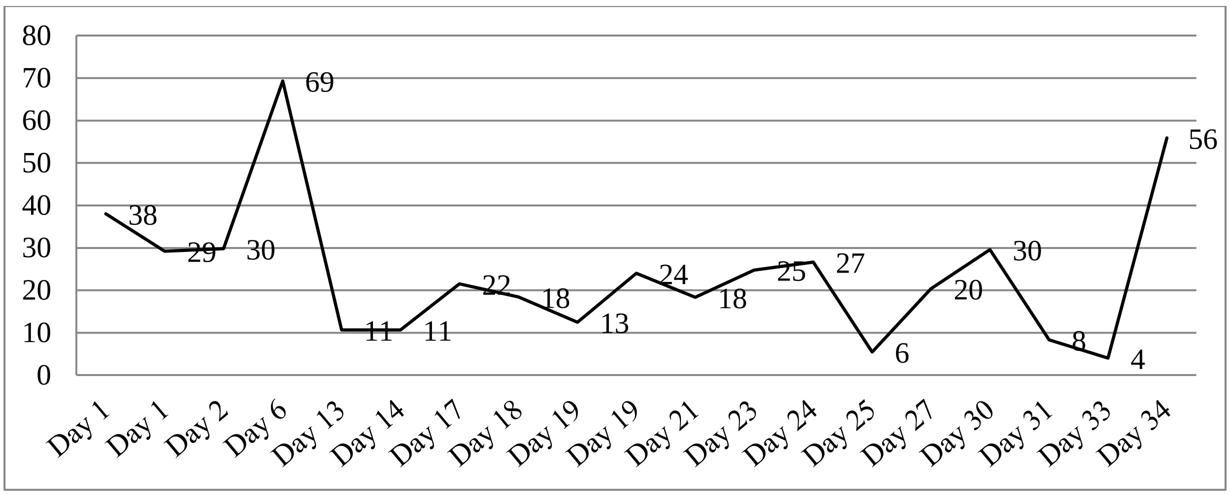


Figure 4-14 A trend in students' use of sources for making meanings (numbers indicate the percentage of students' use of non-intuitive sources)

Summary of Students' Use of Sources for Making Meaning

I explored patterns observed in students' use of sources for making meaning within and across phases. In each phase, students used sources differently to build their ideas. In phase 1, increases in cognitive and linguistic sources influenced students' use of those sources. While their fuzzy understanding became more elaborated, their use of intuitive sources decreased. In phase 2, students' single unit of reasoning was represented by their use of intuitive sources since they projected themselves as writers or speakers into their texts. In phase 3, the different nature of writing tasks affected students' use of sources. In phase 4, the pattern observed in phase 3 became more distinguished. Students tended to use sources differently in this phase depending on the implicit demands of the writing task. Across phases, a general pattern and a unique pattern was identified. In general students gradually used fewer intuitive sources for making meanings through writing as time went on. As a unique pattern, when lots of information or resources were imported or provided via the activities of teacher reading and watching videos, students' use of intuitive sources rapidly decreased.

Exploring Patterns that Emerged in Students' Use of Spoken Discourse

This section explores students' talking. The SWH approach emphasizes students' engagement in socially-negotiated processes in which they exchange, challenge, and debate arguments in order to reach a consensus (Hand, 2008). This public negotiation helps students experience and practice meaning-making and knowledge construction. Therefore, examining students' spoken discourse helps not only to explore how fifth grade students make meanings while engaging in public negotiation, but also to attain a better understanding of how students develop their understanding through writing, since talking plays a different role in the development of students' understanding (Rivard & Straw, 2000). This section explores how students made meanings when they engaged in three different contexts. These three contexts were a) a context that was opened by new Discourse Space, b) a context in which students' ideas were elaborated by teacher reading, and c) a context in which students gave group presentations. To understand the discourses students generated through public negotiation, five components of discourse were examined: a) context, b) purpose, c) strategy, d) text, and e) position.

All three contexts occurred after phase 3, which was identified by the presence of the complexity of reasoning. During phase 1, students mainly generated their inferences. Mrs. Shelly also encouraged them to initiate and share ideas through talking. Therefore, the teacher largely played a directing role to guide students to engage in the topic. During phase 2, students started to limitedly build their own explanations; their initial inferences were further elaborated and developed. However, students were still mainly interested in their own ideas, rather than in negotiation. In other words, students shared their ideas, but they did not actively engage in negotiation. Differing from phases 1 and 2, students in phase 3 started to compare ideas to build scientific explanations. Therefore, exploring spoken discourse after phase 3 will help to better illuminate how students make meanings through public negotiation since students in this phase focused more on developing their understanding through comparing ideas and resources, rather than on simply generating inferences.

To select the three contexts, Mrs. Shelly's modified RTOP scores, observation, analysis of the written discourse, informal conversation, and semi-structured interviews were all used. Table 4-22 summarizes the modified RTOP scores of Mrs. Shelly's lessons for the unit on ecosystems. The scores indicate her level of implementing an argument-based inquiry approach and her students' engagement in that approach. Four categories were used for this study: a) student voices, b) teacher voice, c) problem solving and reasoning, and d) questioning. The average total score of Mrs. Shelly's 28 lessons was 24.3, which could be seen as positioning the teacher at a low level of implementation. Interestingly, the average scores of the categories of "Student Voice" and "Teacher Voice" were relatively higher than those of "Problem Solving and Reasoning" and "Questioning." Table 4-21 summarizes this difference.

Table 4-21 Average Scores on Categories of the Modified RTOP

Category	Student Voice	Teacher Voice	Problem Solving and Reasoning	Questioning
Average Score	1.7	1.7	1.1	1.1

Mrs. Shelly's average score on the modified RTOP was 1.4. The three contexts used for this study were whole class discussion on days 23 and 25, and group 2 presentation on day 28; the teacher's scores on these three days were 1.5/1.4/2.0., which indicated that the three contexts were not below the average. Although it might be difficult to state that the three contexts fully captured Mrs. Shelly's teaching and her science classes, it could be argued that they were not purposefully selected to represent negative aspects of her instruction and class discourse.

Table 4-22 Mrs. Shelly's Modified RTOP Scores

Week	Day	Student Voice						Teacher Voice			Problem Solving and Reasoning							Questioning		Total	Average
		1	2	3	4	5	Average	6	7	Avg.	8	9	10	11	12	13	Avg.	14	Avg.		
1	1	3	2	2	2	1	2.0	1	2	1.5	0	0	2	2	1	0	0.8	1	1.0	23.3	1.4
	2	3	1	1	2	2	1.8	2	2	2.0	1	1	2	2	0	0	1.0	2	2.0	25.8	1.5
	3	3	1	2	3	3	2.4	1	2	1.5	1	0	0	2	0	0	0.5	1	1.0	23.4	1.4
2	4	3	1	1	3	3	2.2	1	1	1.0	0	1	2	1	1	0	0.8	1	1.0	23.0	1.4
	5	3	0	1	2	2	1.6	1	1	1.0	1	1	1	2	0	0	0.8	2	2.0	20.4	1.2
	6	3	0	1	2	1	1.4	3	1	2.0	0	0	1	1	2	1	0.8	0	0.0	20.2	1.2
	7	2	1	0	2	2	1.4	2	2	2.0	0	1	1	1	1	2	1.0	1	1.0	22.4	1.3
3	8	2	0	2	2	3	1.8	2	2	2.0	2	1	2	2	0	0	1.2	0	0.0	25.0	1.5
	9	3	0	1	2	2	1.6	1	2	1.5	1	1	1	2	2	1	1.3	0	0.0	23.4	1.4
	10	2	1	0	2	2	1.4	2	2	2.0	0	1	1	1	1	2	1.0	1	1.0	22.4	1.3
	13	2	0	3	3	1	1.8	2	2	2.0	3	1	1	2	1	0	1.3	1	1.0	27.1	1.6
5	17	2	1	0	2	2	1.4	2	2	2.0	0	1	1	1	1	1	0.8	1	1.0	21.2	1.2
	18	2	0	3	2	2	1.8	1	2	1.5	1	1	3	1	1	0	1.2	1	1.0	24.5	1.4
	19	2	0	2	2	1	1.4	2	2	2.0	2	1	2	1	0	0	1.0	2	2.0	23.4	1.4
	20	3	0	1	2	1	1.4	3	1	2.0	1	1	1	1	1	0	0.8	2	2.0	22.2	1.3
	21	2	0	1	2	2	1.4	2	2	2.0	0	0	1	1	2	1	0.8	0	0.0	20.2	1.2
6	22	2	1	0	2	2	1.4	2	2	2.0	0	1	1	1	1	2	1.0	1	1.0	22.4	1.3
	23	3	0	1	2	3	1.8	2	2	2.0	1	1	1	1	2	1	1.2	1	1.0	26.0	1.5
	24	2	0	1	2	2	1.4	2	2	2.0	1	0	1	1	2	0	0.8	0	0.0	20.2	1.2
	25	2	0	1	1	2	1.2	2	2	2.0	1	1	1	1	2	1	1.2	2	2.0	23.4	1.4
7	26	3	0	1	3	2	1.8	1	2	1.5	1	1	1	2	2	1	1.3	2	2.0	26.6	1.6
	27	2	1	1	3	3	2.0	2	1	1.5	1	2	3	1	1	1	1.5	1	1.0	28.0	1.6
	28	2	1	1	3	3	2.0	1	1	1.0	1	2	3	2	3	3	2.3	2	2.0	33.3	2.0
8	30	2	0	1	3	3	1.8	1	1	1.0	1	2	3	2	1	1	1.7	0	0.0	25.5	1.5
	31	2	1	2	3	3	2.2	1	2	1.5	2	2	3	2	3	1	2.2	2	2.0	34.9	2.1
	32	2	1	0	3	2	1.6	2	2	2.0	0	1	1	1	1	2	1.0	1	1.0	23.6	1.4
	33	3	0	1	2	1	1.4	3	1	2.0	1	1	3	1	2	1	1.5	1	1.0	25.9	1.5
9	34	3	0	1	1	1	1.2	3	1	2.0	1	1	3	1	1	1	1.3	1	1.0	23.5	1.4

Note: A total of 28 lessons were scored.

Context 1: Opening Discourse Space by Framing

Mrs. Shelly used multiple means and activities to open a space for public negotiation. Since this study explored students' use of spoken and written discourse, I investigated a representative example in which Mrs. Shelly opened Discourse Space when students engaged in discussion about their writing tasks.

Talking about Writing Tasks

Discourse on day 24 exemplified how Mrs. Shelly opened Discourse Space, and was frequently observed in her science class. On day 24, Mrs. Shelly opened a space to talk about global warming based upon the writing the students had produced the previous day. Before students engaged in small group discussion to share and elaborate their ideas about global warming, Mrs. Shelly articulated the goal of the writing activity they had completed the previous day (day 23), and briefly shared ideas related to the contents revealed in that writing activity. Table 4-23 presents part of the class discourse that occurred on day 24.

Table 4-23 Episode 1 on Day 24

Teacher	You were supposed to respond as to which individual or students you agree with. First of all, who can tell me what global warming even is? What is it, Michael?
Michael	Global warming is like when the earth starts to heat up and it's not really good for us because sometimes it's not natural.
Teacher	Okay, Sera?
Sera	Global warming is when the atmosphere has a hole in it, which lets more sunlight into Earth to make it warmer.
Teacher	Because the atmosphere, our ozone layer, which is a layer of oxygen and other gases, helps shield and keeps out some of those harmful ultraviolet rays, right? Keeps them out of coming into our atmosphere, and they bounce off. Some do come through, obviously, because that's how we get suntanned and that's why we have sunlight. So some of those rays from the sun do come through. But global warming is a natural thing?
Students	No.
Students	Yes.

Michael	It is except most of it right now is not natural.
Noah	It's from us, we're causing it.
Julia	I don't get it.
Teacher	So global warming is just sort of a natural process because obviously the sun's out there and it's going to heat up our atmosphere, isn't it? But as the note said that I gave you yesterday, it said the seven kids were arguing about what they thought would be the causes from humans with global warming.

In this episode, Mrs. Shelly started her lesson with a question about the students' understanding of global warming. Since there was no discussion regarding global warming on the previous day, this episode represented the students' first engagement in public negotiation to share ideas about or to discuss the topic. Responding to Mrs. Shelly's question, Michael first expressed his definition of global warming. The major idea of his definition was that global warming "is not natural." This idea was not immediately discussed. Instead, Mrs. Shelly asked for Sera's ideas and she described her understanding of global warming by explaining it with a supposition about the thinning ozone layer. Mrs. Shelly briefly articulated Sera's ideas, and then directed discourse into a discussion of whether global warming was a natural phenomenon, which Michael had brought up earlier.

This move of discourse could be understood as Mrs. Shelly's attempt to articulate the intent of the day 23 writing task, which had asked students to explain their reasons for why they agreed with some or all of the seven kids who were arguing about what they thought were the human causes of global warming. Since the writing task considered global warming caused by humans, Michael's ideas were used to articulate the goal of the writing task and group discussion. In other words, Mrs. Shelly highlighted Michael's idea by revisiting it in order to set up the Discourse Space that students were supposed to develop. Therefore, this short episode can be understood as an example of how Mrs. Shelly framed or directed class discourses.

This episode continued to briefly elaborate students' understanding of the contents revealed in the writing task. Students shared their ideas about acid rain, chemicals, and toxins in the atmosphere. This dialogue was wrapped up by Mrs. Shelly's explanation of the next task, wherein she described the small group discussion as follows:

> So you were supposed to circle the names of the people that you thought made the most sense that you agreed with. And then you were supposed to explain why. So you should all have done that. And I asked you to glue this into your notebook, so hopefully you all did that as well. Here's what I'm going to have you do. I'm going to have you group up in small groups of three and share your ideas. You're going to share your ideas of who you agree with and give an explanation of why you agree with that person. [FN, day 23]

In general, the whole class discussion that occurred before the small group discussion aimed to share and elaborate ideas regarding the topic and task in which the students were engaged. At that moment, Mrs. Shelly seemed to focus more on articulating the goal of the tasks (writing and group discussion) than on elaborating students' ideas regarding global warming. To articulate the goal of the tasks, Mrs. Shelly guided whole class discussion by framing discourse. Students participated in class discussion, and the participation occurred mostly when they responded to Mrs. Shelly's questions. Figure 4-15 summarizes these findings in terms of the components of discourse, illustrated on the pentagon model, and figure 4-16 shows a textual analysis that represents the flow of how Mrs. Shelly framed discourse.

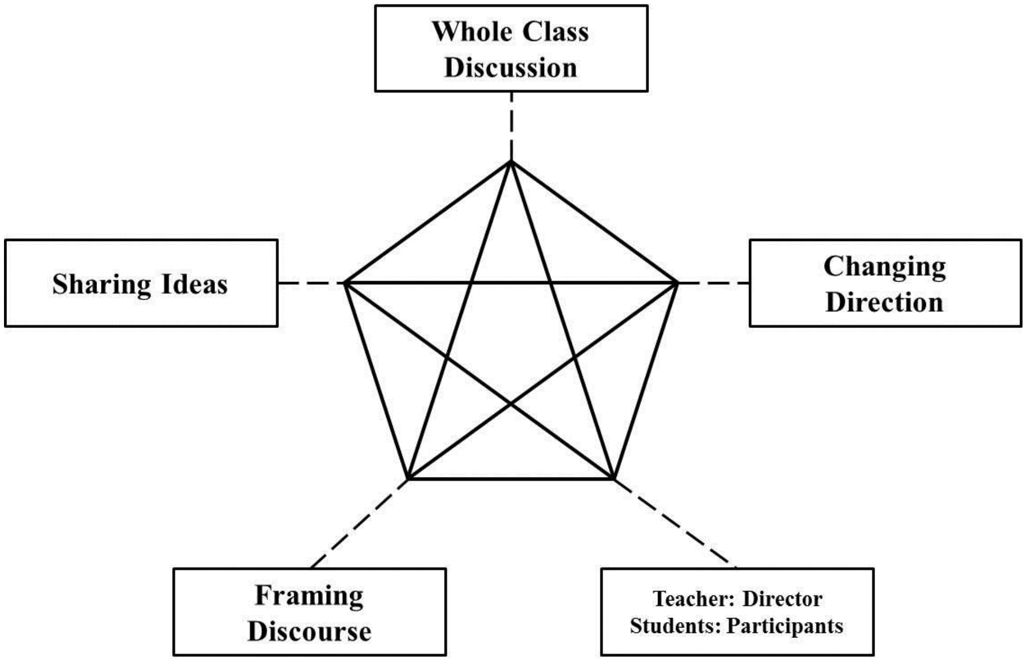


Figure 4-15 Summaries for components of Discourse in episode 1 on day 24

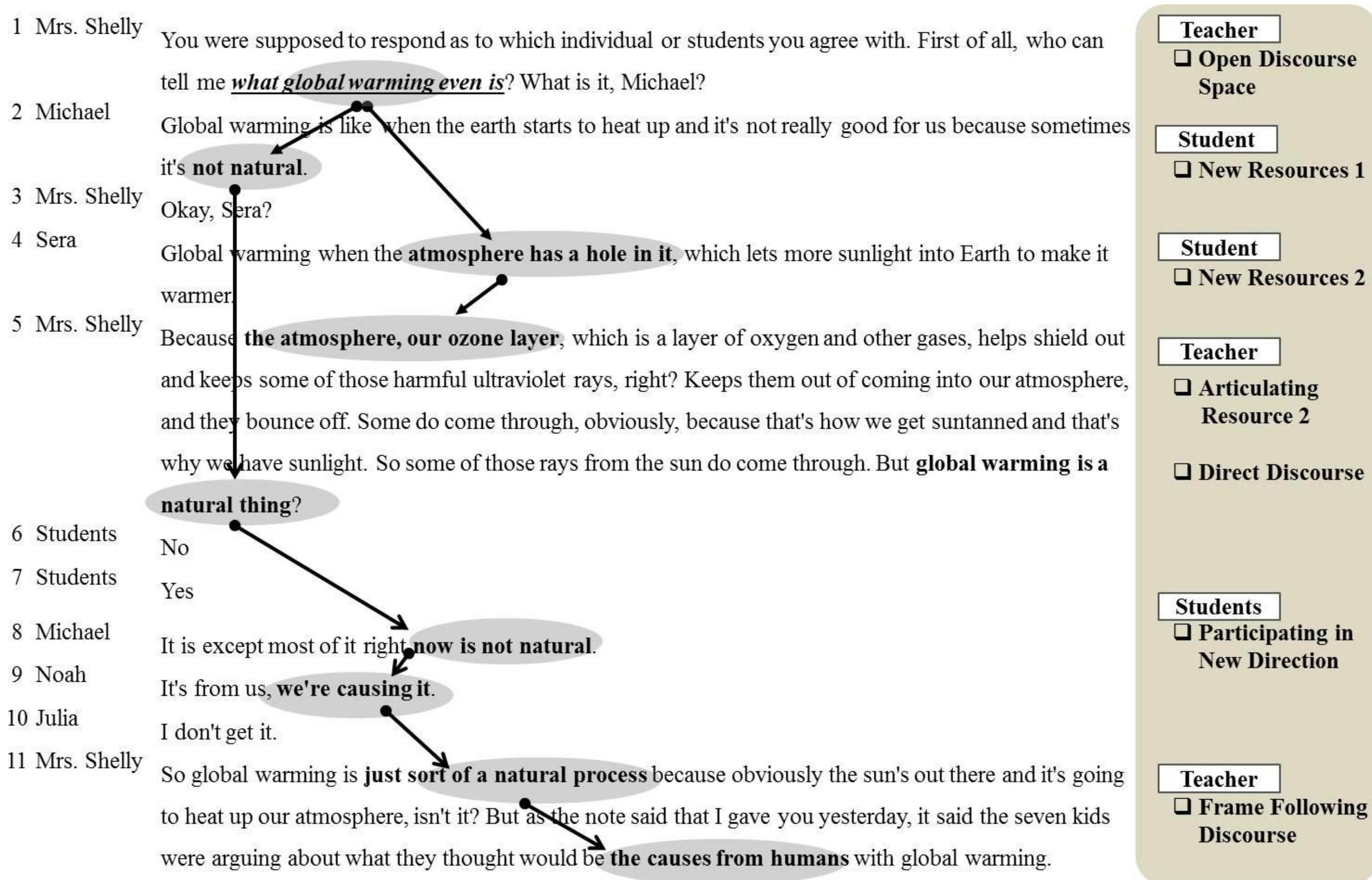


Figure 4-16 A textual analysis of day 24

Context 2: Teacher Reading for Elaborating Ideas

In the second context, Mrs. Shelly used reading as a tool for introducing scientific knowledge to students so as to elaborate their understanding. However, this was not the students' reading activity. Mrs. Shelly read a book out loud to the students and led whole class discussion. In her science classes, she frequently used this reading and discussion strategy. In the semi-structured interview on day 31, Mrs. Shelly discussed her role in the students' learning process. Responding to the interview question, "In science class what is your role in the learning process, where do you fit in?" she stated, "That's a very good question, because I'm still struggling with that. I guess I fit in the fact I'm supposed to be helping direct the students toward the big idea, helping them to discover ideas and questions about the big idea and try to find the answers to those." From her response, it might be reasonable to think of her reading and discussion approach as one of her instructional strategies to help "direct the students toward the big idea."

On day 25, Mrs. Shelly used this reading and discussion strategy, and the discourse on day 25 was selected as context 2. Due to the length of the whole conversation, I chose an episode and then divided the episode in two. These two consecutive episodes were teacher reading and a whole class discussion about saving energy. In her reading, Mrs. Shelly read out loud long paragraphs that averaged two minutes apiece, and students listened to her. Sometimes during her reading, she paused and explained concepts in more detail. She also occasionally asked the students a question, and they responded. Table 4-24 shows the first episode on day 25.

Table 4-24 Episode 1 on Day 25: Framing Discourse

Mrs. Shelly	The burning of fuel produces waste gases that cause air pollution. Things like coal and oil and natural gases are non-renewable resources. Their supplies are limited. Most of the energy we use comes from these fossil fuels. Fossil fuels are fuels that formed in the earth over millions of years. Cars, buses, trains, and airplanes all use fossil fuel. Coal is used by many power plants to make electricity. Natural gas is used in our homes for heating and cooking. If certain gases in Earth's atmosphere such as water vapor, I know last year as a fourth grader, you talked about water. Water vapor, carbon dioxide, methane, they all trap the heat next to the Earth. This keeps Earth's climate warm. Without this, what's called the Greenhouse Effect, most living things on earth would not exist. Okay? So if we didn't have this sort of little… sunscreen, what did you call it?
Michael	Sunscreen.
Mrs. Shelly	Sunscreen or sunblock around the earth, more of the sun's harmful rays will get to it, more of the ultraviolet rays. And it would cause, instead of being deflected back. Some are being deflected back.
Michael	It's like sometimes they offer glasses that they…
Julia	Sunglasses?
Noah	They darken.
Michael	Yeah.
Mrs. Shelly	To protect your eyes.
Julia	Sunglasses?
Michael	Ones that change when you're outside.
Mrs. Shelly	Without this greenhouse effect, most living things on earth wouldn't exist. If more of these gases get into our atmosphere, earth's climate is going to get even warmer. Such a change is called global warming. SHH! Human activities such as manufacturing, burning fossil fuels or raising crops and livestock help create waste gases. Smog is a yellowish gas that sometimes forms over major cities. Smog is a kind of air pollution. It is made when sunlight reacts with pollutants caused by burning fuels. Smog can irritate your eyes. It can make it difficult to breathe.

In Mrs. Shelly's first utterance in this episode, she paused and briefly reminded students of concepts they learned in fourth grade science lessons by stating, "I know last year as a fourth grader, you talked about water." However, there was no further elaboration. She resumed reading, but paused when she read an explanation about the greenhouse effect. Since the students had completed two writing tasks and discussion about global warming two days previously, she might have wanted to revisit or elaborate their understanding of the topic by further explaining the greenhouse effect. However, when Mrs. Shelly used the word "sunscreen" that Michael had brought up, the students seemed to focus more on the individual word even though the teacher also added some explanation of the greenhouse effect. Regardless of her explanation, the students expanded their spoken discourse and ended up by talking about "sunglasses." This might have been influenced by Mrs. Shelly's brief explanation. She seemed to confuse the greenhouse effect with the ozone layer. In utterance 3 in this episode, she used the phrases "sun's harmful rays" and "the ultraviolet rays," which are related to ozone layer depletion, even though the book describes the greenhouse effect that is necessary for living things to exist on the Earth. "Sun's harmful rays" and "the ultraviolet rays" seemed to affect the appearance of conversation about "sunglasses."

The students' conversation about sunglasses was discontinued when Mrs. Shelly resumed reading out loud. There was no further discussion to elaborate their understanding of the greenhouse effect and the ozone layer. When Mrs. Shelly read the sentence "Such a change is called global warming," there was a buzz of conversation since students had discussed this topic two days ago. However, after the teacher said "SHH!," she then resumed reading. Figure 4-17 represents the flow of the first episode on day 25. Table 4-25 shows episode 2, which followed episode 1 on day 25; these two episodes were consecutive.

1 Mrs. Shelly — The burning of fuel produces waste gases that cause air pollution. Things like coal and oil and natural gases are non-renewable resources. Their supplies are limited. Most of the energy we use comes from these fossil fuels. Fossil fuels are fuels that formed in the earth over millions of years. Cars, buses, trains, and airplanes all use fossil fuel. Coal is used by many power plants to make electricity. Natural gas is used in our homes for heating and cooking. If certain gases in Earth's atmosphere such as water vapor, I know last year as a fourth grader, you talked about water. Water vapor, carbor dioxide, methane, they all trap the heat next to the Earth. This keeps Earth's climate warm. Without this, what's called the **Greenhouse Effect**, most living things on earth would not exist. Okay? So if we didn't have this sort of little… **sunscreen**, what did you call it?

2 Michael — **Sunscreen.**

3 Mrs. Shelly — **Sunscreen or sunblock** around the earth, more of the sun's harmful rays will get to it, more of the ultraviolet rays. And it would cause, instead of being deflected back. Som are being deflected back.

4 Michael — It's like sometimes they offer **glasses** that they…

5 Julia — **Sunglasses?**

6 Noah — **They** darken.

7 Michael — Yeah.

8 Mrs. Shelly — **To protect your eyes.**

9 Julia — **Sunglasses**?

10 Michael — **Ones** that change when you're outside.

11 Mrs. Shelly — Without this **greenhouse effect,** most living things on earth wouldn't exist. If more of these gases get into our atmosphere, earth's climate is going to get even warmer. Such change is called global warming. SHH! Human activities such as manufacturing, burning fossil fuels or raising crops and livestock help create waste gases. Smog is a yellowish gas that sometimes forms over major cities. Smog is a kind of air pollution. It is made when sunlight reacts with pollutants caused by burning fuels. Smog can irritate your eyes. It can make it difficult to breathe.

Teacher

- ❑ **Open Discourse Space**
- ❑ **Add Multiple Resources (Reading)**
- ❑ **Reminding Students of Previous Year's Learning Experience, but no Further Elaboration**

Student

- ❑ **Resource 1**

Teacher

- ❑ **Articulating Resource 1**
- ❑ **Add Irrespective Resource**

Students

- ❑ **Expansion of Meanings based on the Irrespective Resource**

Teacher

- ❑ **No link to Students' Previous Utterances**
- ❑ **Keep Adding Resources (Reading)**

Figure 4-17 A textual analysis of day 25: Framing Discourse

Table 4-25 Episode 2 on Day 25: Articulating Ideas

Mrs. Shelly	Ozone, we talked about the ozone layer, is a gas that is a form of oxygen. We talked about the ozone layer, that's really an oxygen layer.
Noah	Is it like an airtight seal so the air doesn't get out?
Mrs. Shelly	It helps seal out the harmful rays. Okay? Ozone protects us from the sun's dangerous rays. But near the ground, ozone is another pollutant that gets into the air when gasoline is burned. Ozone is part of that smog. Burning coal, and two days ago I showed you a little clip video, and it was a song, and it talked about acid rain. When these chemicals combine with moisture in the air, they form acids in the air. Julia, when I'm talking and we're having a discussion, everybody should be in their seat. Acids are chemical compounds that react easily with other substances. The acid water in clouds falls back down to earth as rain, that's what we call acid rain. Acid rain, as that video showed the other day, can actually harm buildings. It can eat away or erode the rocks in the buildings. It can erode or eat away at statues and monuments.
Noah	Like the Statue of Liberty.
Mrs. Shelly	So it can harm things. It causes rust sometimes. Acid can damage buildings, statues, and other things by dissolving the stone that they're made of. So it can actually eat away at it. That is a major concern, yeah. It's hard to find ways to keep our air clean, but we have to do that. One simple way is to use less fossil fuel. What are fossil fuels again, Merry?
Merry	They're animals that decay in the ground.
Mrs. Shelly	Okay, so oil that we've made fuels out of from millions of years of buildup of decaying plants and animals. Using less of a natural resource is called conservation. Conservation of fossil fuels reduces pollution and will make our supply of fuel last longer. Many of you have seen as you go down the highway, you see those great big white windmill tanks or the big blades. They are made not too far from here and they travel a lot down the highway. They're made over by West Branch, the big blades and stuff. Some parts are made in Cedar Rapids, some in Des Moines. They travel down 380 a lot and they go and stockpile up by where my son lives in Cedar Falls. There are a bunch of these big wind turbines out in Carol, Iowa. A bunch outside Cedar Falls. And soon there's going to be a bunch of them up by Solon. Solon, Iowa. Up by the reservoir. It looks like this. You've probably all seen these going down the highway at some point, or seen them out in the big field.
Class	[talking over each other]
Mrs. Shelly	So wind power is one way to help us to conserve our fossil fuels. By harnessing the wind. Iowa's a pretty windy state. So if we can use more of these to make energy, then we're using less fossil fuels and less coal. Cars can pollute the air with their exhaust. And so that fossil fuel exhaust is going into our air. People can help reduce air pollution by using less fuel. What are some things we could do to help us use less fuel? What's one thing Ivy?
Ivy	We could instead of using fuel…
Mrs. Shelly	What do you do to get to school?
Ivy	Carpool sometimes.
Mrs. Shelly	Okay, you carpool because what happens? What happens when you carpool?
Ivy	We don't use as much fuel.

In episode 2, observation was focused on how Mrs. Shelly dialogically interacted with students when providing new scientific content knowledge and elaborating students' understanding. First, a traditional triadic pattern, initiation-response-feedback (IRF) was observed. This dialogical pattern was initiated by the teacher's questions. For instance, Mrs. Shelly asked Merry, "What are fossil fuels?" and later asked Ivy, "What are some things we could do to help us use less fuel? What's one thing Ivy?" These questions initiated a short dialogue between the teacher and a student. In this episode, Mrs. Shelly asked simple questions to elicit factual knowledge, so that the dialogue in which the IRF pattern was observed was short.

A similar pattern to IRF was also identified in this episode. In this pattern, the teacher did not attempt to initiate dialogue. Instead, students initiated dialogue. Some words, contents or meanings in the teacher's utterances or reading stimulated the students' interests. For instance, Mrs. Shelly's explanation of the ozone layer initiated Noah's question, "Is it like an airtight seal so the air doesn't get out?" Mrs. Shelly briefly responded to his question, "It (the ozone layer) helps seal out the harmful rays." Similarly, while Mrs. Shelly read out loud about acid rain ("It can erode or eat away at statues and monuments"), Noah broke into her reading, and said "Like the Statue of Liberty." He likely paid attention to a word, "statue," instead of to the scientific content of Mrs. Shelly's reading. Similar to the IRF pattern in episode 2 on day 25, the dialogical interaction between the teacher and the student was short, and was not expanded to develop students' understanding.

In summary, Mrs. Shelly's reading seemed not to encourage students' active engagement in the scientific content provided by her reading, or in their thinking about that content. Mrs. Shelly's intent of reading was seen as providing scientific knowledge and elaborating students' ideas. However, considering the dialogical interactions between the teacher and her students, and the teacher's questions, the dialogical patterns revealed in episodes 1 and 2 on day 25 indicate that Mrs. Shelly seemed to focus more on providing scientific information through reading and checking students' factual knowledge, rather than on further elaborating their understanding. In this sense, her questions focused on students' factual knowledge related to the contents of the book she read out loud. Consequently, the development of vertical Discourse Space was not identified during these two episodes even though the teacher provided lots of information through reading. Figure 4-18 summaries these findings in terms of the components of discourse, illustrated on the pentagon model. Figure 4-19 shows the process of meaning making in episode 2 on day 25.

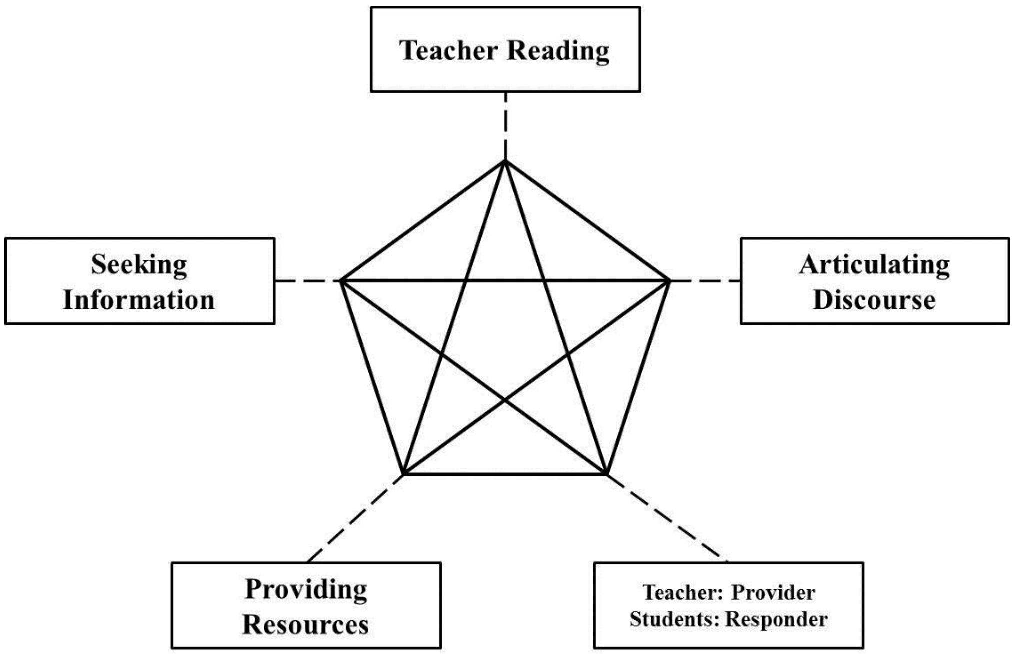


Figure 4-18 Summaries for components of discourse in episode 2 on day 25

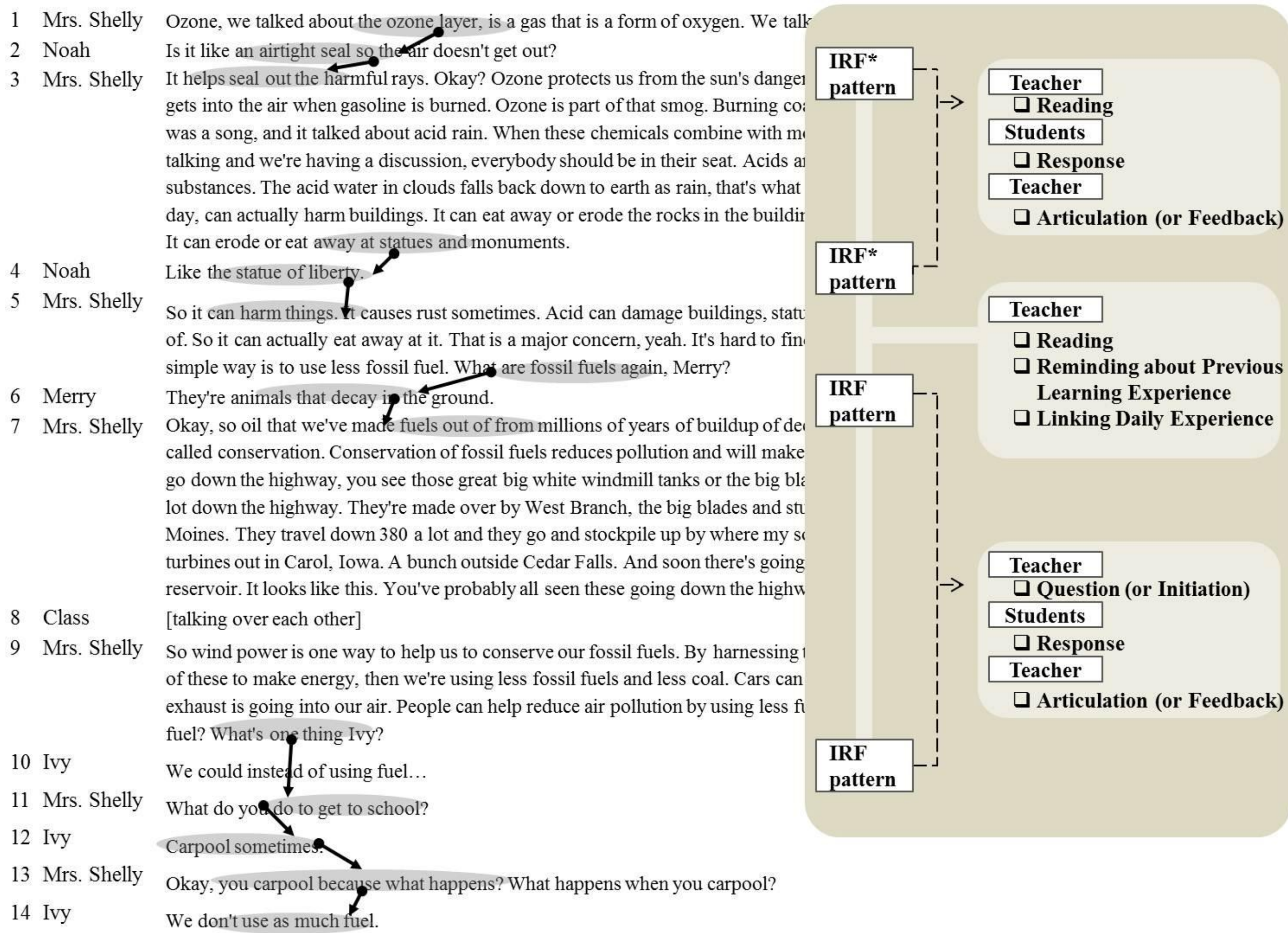


Figure 4-19 A textual analysis on day25: Articulating Ideas

Context 3: Student Presentations and Evaluation

From days 28 to 31, students engaged in group presentations. They had investigated their groups' questions for approximately one month, and had engaged in multiple activities that helped to elaborate and develop those investigations. In group presentations, group members presented their initial idea, claim, evidence, testing procedures, and reflections. During these presentations, students mostly led classroom discourse, and Mrs. Shelly occasionally participated in the discourse. This section discusses two episodes related to group presentations. In the first episode, I explore how Mrs. Shelly and students set up the rules for negotiation. In the second episode, I investigate how public negotiation for making meanings occurs in group presentations.

Setting up Rules for Negotiation

The first episode took place before group presentations on day 28. In this episode, Mrs. Shelly and students shared rules for negotiation, and seven rules were articulated: a) "talk about it to the audience" ("speaking up" and "stating information clearly"), b) "no yelling," c) "one at a time," d) "no need to raise hands," e) "wait until the previous person gets finished," f) "listening" ("trying to listen and we're trying to understand question and evidence better"), and g) "not trying to prove them wrong" ("It's not an argument."). Rules were created and shared by the teacher and students' dialogical interactions. Mrs. Shelly articulated the students' utterances, as well as facilitated discussion to clearly share rules for negotiation. These shared rules not only served as fundamental norms that framed Discourse Space, but also functioned as a guide to help students participate in public negotiation. The first to fifth rules are seen as rules for students as speakers, while the sixth can be linked to a rule for students as listeners. The seventh rule informs students of the nature of negotiation. Table 4-26 shows Episode 1 on day 28, and figure 4-20 illustrates the process of setting up rules for negotiation.

Table 4-26 Episode 1 on Day 28: Setting Up Rules for Negotiation

Teacher	What is it? Steve, negotiation.
Steve	Um, to like talk about it to the audience. Or like to talk really loud and say to the audience, to say something out there.
Teacher	Okay, so it is important when we're having a conversation, because it's like a big group discussion, isn't it? That's really what we're doing. When we are having that, you need to make sure that you're speaking up so that everybody can hear, right? And make sure you're stating your information clearly, whether you're sharing your claim and evidence or whether you're in the audience having questions for them. Okay. What else do we need to remember about negotiation, after they're done sharing their claim and evidence?
Julia	No yelling.
Teacher	Right, it's not yelling. It's not, what else?
Julia	Talking over someone else's words.
Teacher	Right. One at a time, exactly. It's not trying to talk over somebody. What else?
Steve	I wanted to ask, do you have to write a question for each one?
Teacher	You mean for each of the groups? Hopefully if they're sharing, you'll have questions come up or you'll have thoughts come up that you want to talk with them about. Okay. So we're not going to try and talk over. Remember, one person at a time can talk. Do they need to raise their hands? Is that required or necessary?
Students	No.
Chloe	We should be able to be more adults.
Teacher	Exactly. There are times when you're in a group meeting that people always raise their hand. That doesn't always happen, does it? Sometimes it does. But most of the time it doesn't. Right, wait until the previous person gets finished. Just be respectful, okay? And what are those of us in the audience trying to do?
Julia	Listening.
Teacher	We're trying to listen and we're trying to understand question and evidence better, right? Okay. Is it like we're trying to prove them wrong?
Chloe	No. You're just trying to support your claim of what you think will, "Did this happen, do you think this will happen?" Trying to give them a little bit of what you think or your little idea to help them with the claim that you think.
Teacher	Okay. Sometimes it's kind of like we're playing what's called Devil's Advocate, which means we're trying to sort of stump them a little bit. But we're doing it respectfully, aren't we? Okay. It's not an argument. Alright. So, everybody's groups ready? Can I ask you to be ready? Okay.

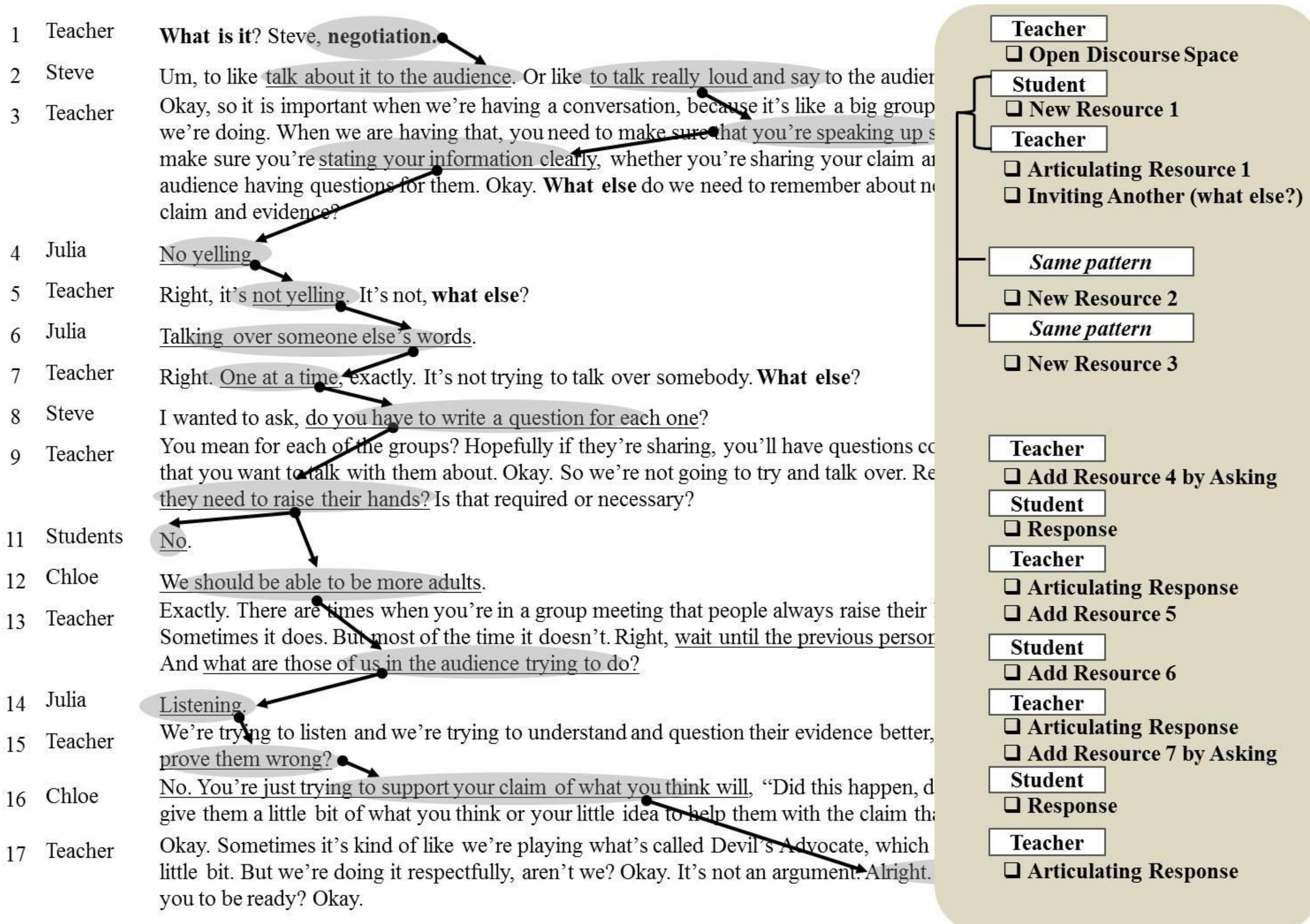


Figure 4-20 A textual analysis on day 28: Setting up Rules for Negotiation

Negotiation and Articulation

On day 28, students had two group presentations. Each group on average spent fifteen minutes presenting about and discussing the group's investigation. After the group 1 presentation, Mrs. Shelly again reminded the students about the rules for negotiation, and the four students in group 2 (Chloe, Ruby, Julia, and Katy) began their presentation by explaining the group's inquiry question, beginning understanding, test procedure, claim, evidence, and information they found from books. Group 2 had investigated their inquiry question, "What lives in pond water?" Table 4-27 represents group 2's presentation.

Table 4-27 Episode 2 on Day 28: Group Presentation

Julia	Our question is, what lives in pond water?
Katy	Our beginning understanding was bacteria. Steps: Step one, get pond water. Next step, get a bottle. Third step, then put the water in the bottle. Fourth step, examine.
Chloe	First we saw two bugs in the water and a leaf. And we tried to get the bugs out with the eyedropper, so then Julia killed them. Shannon got the bugs out with an eyedropper. And we looked in the microscope and saw bugs. And then a couple days later, yeah, the water was just intestine-y.
Julia	This is one, right there.
Chloe	The other bug looked like it got eaten. One of the bugs was tan and fuzzy. It was a little furball. And the other bug had an orange back and it had four legs. And it looked like a water skater. It was really really small.
Ruby	Our big plan was that I think the bugs died because the glass bottle was closed so they couldn't breathe.
Julia	Our evidence is in pond water there is bugs, insects, fish, plants, and animals.
Chloe	Those include pond snails, pond skaters, snapping turtles, tadpoles, plants, crayfish, frogs, insects, and bacteria.
Julia	There are three different kinds of pond water. It's, what was it called?
Chloe	Alpine, bog, and stream, or tundra.
Julia	Those are four.

The four students read each part of their group writing. Group 2's inquiry question was "What lives in pond water?" In group 2's presentation, their beginning ideas and claim were not clearly presented. Moreover, they did not explicitly present how their evidence was created. Chloe explained her group's observation of the pond water. When describing the procedure of observations of the bugs in the sample water, she mentioned that, "… Julia killed them." This statement initially stimulated students' engagement in public negotiation. After the presentation, students started to ask questions, and public negotiation began. Table 4-28 illustrates the public negotiation that occurred right after group 2's presentation on day 28.

Table 4-28 Episode 2 on Day 28: Public Negotiation

Michael	Why did you kill the bugs?
Julia	Because we couldn't get it in the squeezy thing.
Sera	Why did you need the squeezy thing?
Chloe	We needed to put it in so we could put it on the microscope slide.
Julia	I killed it and then put it on.
Michael	But why did you kill it?
Julia	Because it was moving around.
Michael	Why did you need to put it on the microscope?
Chloe	We wanted to look at it closer. We wanted to get the bug on the microscope…
Noah	We didn't even have microscopes that day.
Chloe	Yeah we did. We got one.
Noah	How did you even get the bug on the slide? It's too big and it would start walking off.

Chloe	We killed it. That's why we killed it, so it would stay still and not crawl around and then people start screaming.
Michael	You didn't exactly answer your question. You just killed the bugs and then…
Chloe	Well we asked what lives in pond water. We found it.
Michael	Well yeah but you didn't figure out what kind of bug. You just said it's fuzzy.
Chloe	No, we said it was fuzzy and it was tan.
Julia	And we found one that was orange and it only had four legs on it.
Michael	You squished it, so you don't exactly know.
Chloe	We didn't squish it.
Julia	We didn't squish the fuzzy one, the fuzzy one was already dead.
Michael	You said you killed all of them.
Hardman	Who got the pond water?
Julia	Me. From my pond.
Michael	What kind of pond water?
Chloe	A natural pond.

In this episode, students negotiated ideas to articulate information. They discussed why group 2 needed to kill the bugs. First, through their presentation, presenters (members of group 2) opened Discourse Space and provided lots of information about their group's investigation in it. Participants (the audience) in the Discourse Space started to engage in the information and attempted to understand it. Since the audience members had some difficulty understanding the information, they asked questions or made comments to articulate the ideas that had been illustrated by the presenters. The presenters, on the other hand, articulated their own information to more clearly present their ideas, so as to help participants better understand them. During this process both presenters and participants articulated the information, and the articulated information could serve as a resource to obtain a better understanding of the group investigation.

Throughout several cycles of negotiation, participants came to learn the reason why the group 2 students killed the bugs. The reason was that the students wanted to put the bugs on the microscope slide for closer examination. Although the presenters articulated the reason for killing the bugs, they wanted more detailed information and further explanation about the group 2 investigation. For example, Michael pointed out, "You didn't exactly answer your question." Chloe (one of the group 2 members) responded to Michael's point by saying, "Well we asked what lives in pond water. We found it." However, the group 2 students "didn't figure out what kind of bug [it was]," as Michael argued, and did not make any attempt to link the investigation to the big idea of the unit. This critique generated by Michael was, however, disconnected by questions to articulate the procedures of the group investigation. This interpretation could be supported by interview data with Mrs. Shelly. In the interview, Mrs. Shelly reflected on this group's investigation as follows:

> …Four of my students were using pond water as a question, what lives in pond water, I believe. And they went out and explored the pond and found animals and plant life and things like that. Ideally, what I would have liked them to have done more was to take a look at the pond water to see what things are actually living in it, a small sample. And they did once but it didn't really pan out the way I would have liked it to. [Interview with Mrs. Shelly, day 31]

During group 2's presentation, Mrs. Shelly did not actively participate in discussion. When she did participate in discourse, she usually asked a question to articulate students' utterance such as "What were the other ones? Did you say tundra, alpine, bog, and stream?" or to manage dialogical interactions such as "Can you wait, they need to answer this question." On the other hand, group 2 students did not clearly present how they structured reasoned evidence. In the interview, Mrs. Shelly also reflected on the role of evidence in her classroom related to this unit. She stated that,

> Well, it (evidence) should play a significant role. I'm really struggling with that this year. The evidence that the kids have been presenting with this first unit (ecosystems) has really been very very weak. So I know it should be what they have found out from their question, but it doesn't necessarily always work that way. So it's been a challenge. [Interview with Mrs. Shelly, day 31]

Figure 4-21 represents how this articulating and evaluating process occurred in public negotiation on day 28.

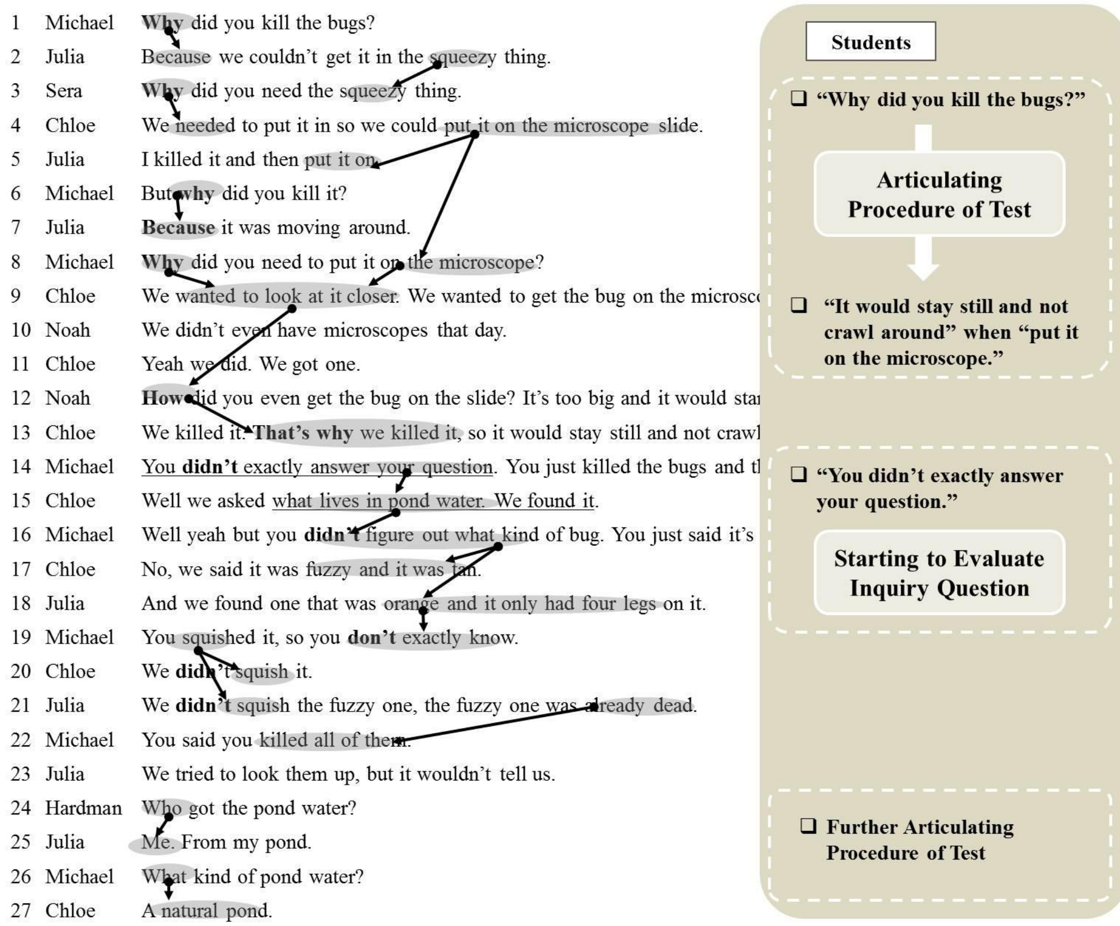


Figure 4-21 A textual analysis on day 28: Limited Public Negotiation

In summary, these episodes on day 28 illustrate how public negotiation occurred in group presentations. Before group presentations, Mrs. Shelly and her students set up the rules for negotiation. Most of these rules were related to what students as speakers need to do, which might help to create a non-threatening learning environment. Other components that focused on listening and the nature of negotiation, which might promote the quality of argument students generate, were highlighted less. Within this setting, students in group 2 presented their group's investigation. However, their use of evidence to support their claim was vague and not explicitly presented. As a result, in discussion, most of the utterances were associated with students' attempts to articulate information.

Some evaluation occurred, but it was not further developed. In addition, the teacher or students' attempts to link the group investigation to the big idea of the unit were not identified. Figure 4-21 and figure 4-22 summarize these findings in terms of the components of discourse, illustrated on the pentagon model.

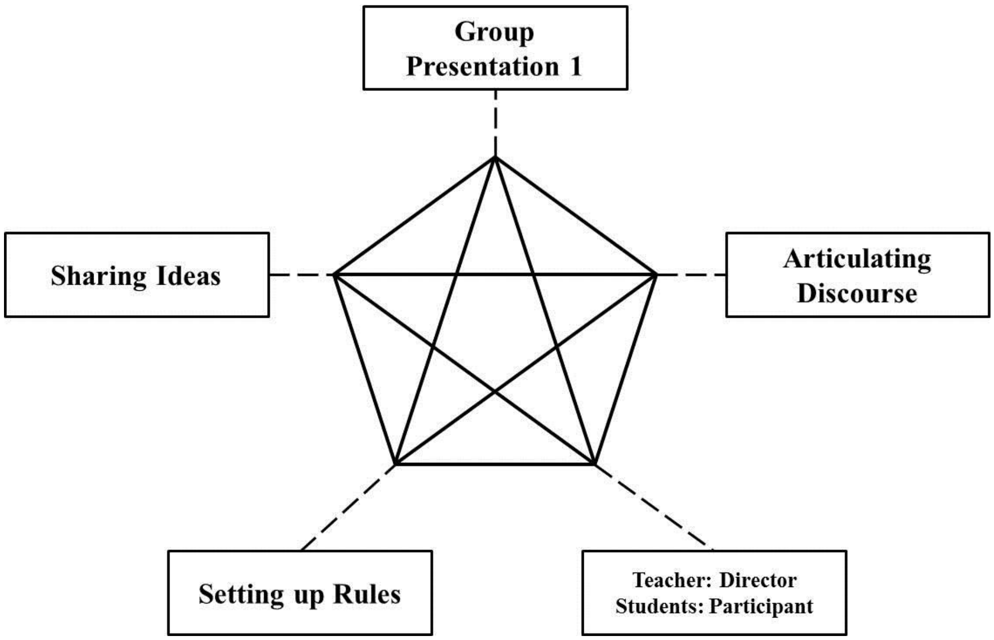


Figure 4-22 Summaries for components of discourse in episode 1 on day 28

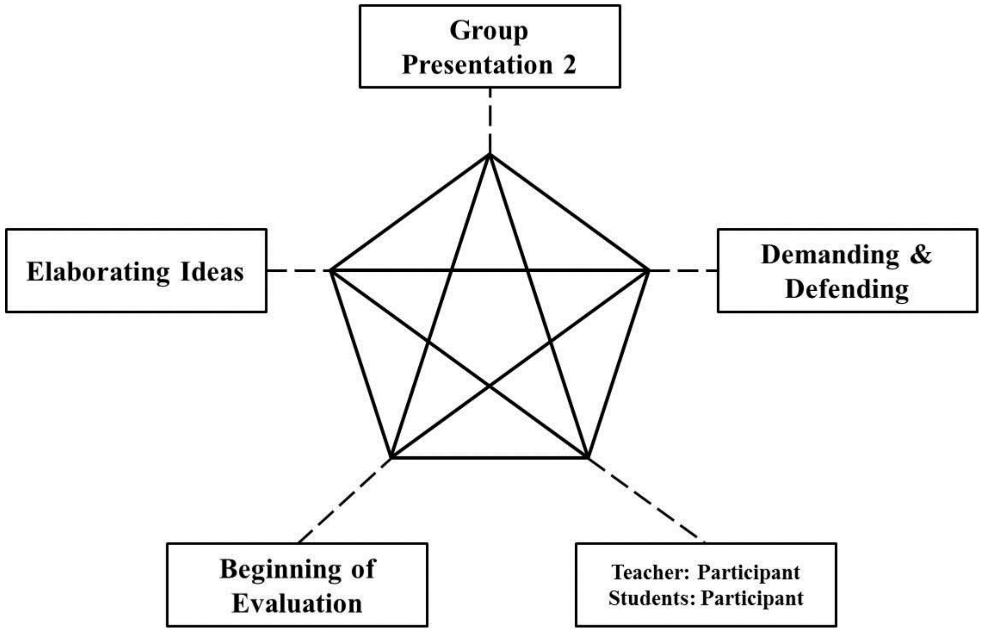


Figure 4-23 Summaries for components of discourse in episode 2 on day 28

Summary of Exploring Dialogical Interactions

The engagement of Mrs. Shelly and her students in dialogical interactions was explored in this section. Three contexts occurring after phase 3 were examined because at that point students started to engage in negotiation beyond generating and simply sharing their own inferences. These three contexts were a) a context that was opened by new Discourse Space, b) a context in which students' ideas were elaborated by teacher reading, and c) a context in which students gave group presentations. To understand the discourses students generated through public negotiation, five components of discourse were examined: a) context, b) purpose, c) strategy, d) text, and e) position. In the first context, the teacher framed discourse to guide students, and students' engagement in this dialogical interaction was limited. In the second context, the teacher focused more on providing scientific knowledge and checking students' factual knowledge, rather than on elaborating and further negotiating ideas related to the topic. In the third context, students presented their group investigation, and as a result they engaged more actively in presentation and discussion. The teacher did not actively participate in the discussion, and students' discussion focused mostly on articulating information. Few evaluating questions such as critiquing and challenging ideas appeared.

Summary of Chapter

In this chapter, I examined students' writing and talking when immersed in an argument-based inquiry approach to explore the development of cognition through writing and the pattern of Discourse Space development that emerged in students' written and spoken language. This chapter consisted of two parts: a) I examined the changing patterns that emerged in students' use of written language over time, and b) I examined verbal discourse patterns that appeared when students engaged in three different contexts. In the first part, I described six fifth grade students' reasoning development over time and the patterns observed in their use of sources for making meaning within and across phases. Two major findings were discussed in this part: a) all six fifth grade students' reasoning developed over time, and b) students' use of sources for making meanings changed over time. In the second part, I described the teacher and students' engagement in dialogical interactions based on three different contexts. One major finding was discussed in this part: students as participants in discourse had limited opportunities and demands to engage in dialogical interactions. In the next chapter, I will discuss how these findings contribute to an understanding of the development of students' cognition through language, promoting their engagement in type 2 processing and helping them to grasp scientific practice, and I will raise a critical issue, highlighting the importance of language in science classrooms by proposing a new concept of Discourse Space.

CHAPTER FIVE

DISCUSSION

This study aimed to explore the development of student cognition through writing and the pattern of Discourse Space development that emerged in students' use of written and spoken language. In this study, participants were immersed in an argument-based inquiry approach that encouraged them to engage in private and public negotiation under a teacher who is ranked as a low-level implementer of the SWH approach. This chapter summarizes this study by addressing the research questions, and then discussing the findings. Additionally, the theoretical and pedagogical contributions of this study are discussed. Finally, the limitations of the study and future research are examined.

Summary of Findings

The first research question for this study investigated how students develop their understandings through writing. Writing samples produced by six fifth grade students during a unit of ecosystem were examined. During this unit, each student produced an average of 36writing samples, and a total of 216 of these samples were investigated in terms of their complexity of reasoning and students' use of sources for making meanings. The second research question for this study investigated the dialogical patterns that the teacher and fifth grade students created, and how those patterns changed when students engaged in different settings of public negotiation. Three different contexts were explored to understand how participants in discourse made meanings through talking.

Exploring Students' Use of Written Language

Students' writing was examined in terms of reasoning complexity and their use of sources for making meanings. In terms of the complexity of reasoning, all six students' reasoning developed over time, and four phases were identified based on this development. The first phase appeared in weeks 1 and 2. In this phase, students' writing samples from days 1 to 6 illustrated their initial inferences about the topic. These initial inferences exhibited the students' fuzzy understanding, and no reasoning structure or scientifically acceptable explanations were found in the students' writing. The second phase appeared in week 4. In this phase, a *single unit of reasoning* was identified in all students' writing samples on day 19. This *single unit of reasoning* seemed to help students explore alternatives so as to build their own explanations of natural phenomena based upon their initial inferences. However, the level of explanation students generated was identified as low. Their explanations were limited to summarizing or describing the patterns they inferred from their hypothetical thinking. The third phase appeared in week 6. In this phase, students started to compare some ideas and resources to build up and present more complex and scientifically valid ideas. A developing *chain of reasoning* first emerged in a student's writing sample on day 24; however, not all students developed their chain of reasoning at this time. Furthermore, the students did not yet utilize multiple resources to build coherent explanations. In this study, phase 3 marked the intermediate phase that bridged the process of seeking alternatives (phase 2) and the process of comparing ideas (phase 4). The final phase appeared in week 9. In this phase, students completed a summary writing task on day 34, and in their texts, the chains of reasoning were identified, and their explanatory power was increased. Despite an ongoing trend toward increasing elaboration, the data analysis, however, suggested that the students' explanations still required more elaboration. Even by the end of phase 4, students still used limited resources and ideas to build their own explanations, and the level of scientific explanation generated was characterized as lower middle.

Students' use of sources for making meanings was also examined, and the patterns of students' use of sources within and across phases were explored. First, the patterns within phases were investigated. In phase 1, increases in cognitive and linguistic sources influenced students' use of those sources. The increases helped to slightly elaborate their fuzzy understanding, and their use of intuitive sources decreased. In phase

2, students' single unit of reasoning was represented by their use of intuitive sources. In their writing, students projected themselves as writers or speakers into their texts. In phase 3, the different nature of writing tasks affected students' use of sources. In phase 4, the pattern observed in phase 3 became more distinguished. Students tended to use sources differently depending on the implicit demands of the writing task. When exploring patterns of students' use of sources across phases, a general pattern was identified even though some writing samples illustrated a pattern inconsistent with the whole. In general, as time went on, students gradually used fewer intuitive sources for making meanings through writing. Additionally, a unique pattern was also detected. When lots of information or resources were imported or provided via the activities of teacher reading and watching videos, students' use of intuitive sources rapidly decreased.

Exploring Students' Use of Spoken Language

Students' talking was examined not only to explore how fifth grade students make meanings while engaging in public negotiation, but also to attain a better grasp of how students develop their understanding through writing, since talking plays a different role in the development of students' understanding. This section explores how students made meanings when they engaged in three different contexts. These three contexts were a) a context that was opened by new Discourse Space, b) a context in which students' ideas were elaborated by teacher reading, and c) a context in which students had group presentations.

The first context occurred when the teacher opened a whole class discussion about the students' writing tasks. This whole class discussion occurred in week 6 (phase 3 in terms of the complexity of reasoning: students started to compare ideas). In this context, the teacher seemed to focus more on articulating the goal of the tasks (writing and group discussion) than on elaborating students' ideas about the topic. To articulate the goal of the tasks, the teacher guided whole class discussion by framing the discourse. Students participated in class discussion, and this participation occurred mostly when they responded to the teacher's questions.

The second context was a whole class discussion initiated by the teacher's reading. This whole class discussion occurred in week 6 (two days after the first context). The teacher's reading did not seem to encourage students' active engagement in the scientific contents her reading provided, or in their thinking about those contents. The goal of reading was seen instead as providing scientific knowledge and elaborating students' ideas. However, considering the dialogical interactions between the teacher and her students, and the teacher's questions, the dialogical patterns that emerged indicated that she seemed to focus more on providing scientific information through reading and on checking students' factual knowledge, rather than on further elaborating students' understanding while reading the book.

The third context was group presentation. Group 2 students presented their group investigation and led discussion in week 8. Before group presentations, the teacher and students set up rules for public negotiations. Most of these rules were related to what students as speakers need to do, which might help to create a non-threatening learning environment. Other components that focused on listening and the nature of negotiation, which might promote the quality of argument students generated, were less highlighted. Within this setting, students in group 2 presented their group's investigation. However, their use of evidence to support their claim was vague and not explicitly presented. From this point on, in discussion, most utterances were associated with students' attempts to articulate information. Some evaluation occurred, but it was not developed further. In addition, the teacher and students did not explicit their attempts to link the group investigation to the big idea of the unit.

<u>Discussion of Findings</u>

In this study, the view of how scientific literacy is achieved was grounded in Klein's (2006) theoretical suggestions. Klein re-conceptualized scientific literacy by drawing from two different perspectives of cognition (first generation/second generation of cognition), and discussed these two perspectives, focusing on three shifts in terms of reasoning, the use of language, and knowledge construction. Although Klein (2006) highlighted the second generation of cognition, he was not suggesting that there is a right or wrong between the two different generation theories when adopting them in science classrooms. Instead, he argues that there is a difference between the two approaches, and that each is beneficial to the learning and teaching of science. He continues to argue that science literacy education needs to mediate between the relatively denotative nature of science texts and the expressive nature of everyday thought and language.

But how does science literacy education promote the mediation or negotiation between these two different cognitions? I argue that students' engagement in type 2 processing, drawing form dual processing theory (Evans, 2008; 2010; Stanovich, 2004; 2011), can serve as the vehicle to mediate the three shifts suggested by Klein. Students' engagement in type 2 processing in science classrooms means that they engage more in the process of evaluation. The learning environment, instruction, and teacher encourage students to evaluate resources or ideas which they can access at a certain moment. This engagement in evaluation can help students not only constitute new knowledge beyond their inferences in order to move toward scientifically plausible explanations regarding natural phenomena, but also to build their understanding of scientific practice by performing both the roles of critiquer and constructor. With this in mind, examining the complexity of reasoning and students' use of language revealed in their writing helped to explore students' engagement in type 2 processing, as well as the development of understanding over time. Additionally, exploring students' engagements in public negotiation also contributes to an understanding of the learning demands that encourage students to engage in type 2 processing. In the following section, these relationships will be discussed based on the findings of this study. First, the relationships among the development of the complexity of reasoning, understanding, and the engagement in evaluation are discussed; then examination of the relationships among the use of language, understanding, and the engagement in evaluation follows. This section ends with a discussion of how a concept of Discourse Space can be linked to these findings.

Reasoning Complexity, Evaluation, and Understanding

The increasing complexity of reasoning revealed in students' texts indicates that over time students engaged more in the evaluating process, which helped them to achieve a Discourse of Science, rather than to comprehend the content knowledge of science. In this study, four phases were identified in terms of the complexity of reasoning. As the first finding, the data analysis indicates that all six fifth grade students' reasoning developed over time, but it did not become fully developed. This development could be discussed based only on the extent of the sophistication of the students' conceptual understanding of the topic. However, this study explored this development with regard to the emergence of type 2 processing when students engaged in cognitive processes to build their ideas. In other words, this study suggests that more complicated reasoning indicates not only the development of students' understanding of the topic, but also of students' increased engagement in type 2 processing. For example, a *chain of reasoning* requires students to engage more in the process of evaluation than they do when using a *single unit of reasoning*. To create a *chain of reasoning*, students need to compare multiple ideas and resources available to them at a certain time. Moreover, they need to explicitly connect several ideas or concepts, rather than simply displaying all of the information or resources currently available to them. Therefore, evaluation, which is seen as the core of type 2 processing, plays a key role in the comparison and synthesis that help students develop their understanding.

Additionally, constructing and understanding scientific knowledge and scientific reasoning fundamentally requires this evaluation process. Scientific knowledge does not simply emerge. Some people might learn the story of Newton sitting under an apple tree and observing an apple fall to the ground. When he saw the apple fall, Newton began to think about a specific kind of motion. After hearing this story, people may believe that this is the process through which new scientific knowledge is created. However, in reality, scientific knowledge has advanced or developed based upon previous scientific knowledge only when newly proposed knowledge goes through critical evaluating systems in the scientific community. Additionally, proposing new knowledge itself requires the critical evaluation and review process in order to provide more plausible evidence to build scientific explanations regarding natural phenomena. Therefore, without the emergence of type 2 processing, it might be difficult not only to understand how scientific knowledge is constructed, but also to grasp a scientific practice that requires the ability to play the roles constructor and critiquer.

Moreover, interpreting and understanding scientific knowledge requires evaluation. The scientific knowledge that students encounter is a kind of representation of nature, and can only be represented by language. To interpret and comprehend scientific knowledge represented by language, a student as an individual needs to engage in privately negotiated processes among his or her current understanding, the representations and the resources available to him or her in a particular moment. Through an active evaluation process, he or she needs to choose, compare, apply, analyze, and synthesize possible resources to gain a better understanding of natural phenomena. If he or she engages in socially negotiated processes, he or she can obtain more opportunities not only to share, create, and elaborate resources, but also to further engage in evaluating processes. Therefore, to interpret and understand scientific knowledge, students' engagement in type 2 processing (evaluation) is also required.

From these two reasons, it can be argued that students' engagement in type 2 processing is necessary to understand not only how to construct scientific knowledge, but also how to interpret and understand scientific knowledge. However, it can be difficult to directly access students' cognitive processes in order to assess whether they are engaging in type 2 processing at any given moment. Although there are several approaches to measuring students' cognitive skills, those measures tend to focus only on those skills that are decontextualized from the learning process. As an alternative to these approaches, exploring the complexity of reasoning revealed in texts that students produced while learning scientific concepts served as a mirror to illustrate not only how students engaged more in type 2 processing, but also how they developed their understanding over time.

However, in this study, the students' complexity of reasoning was not fully developed. In participants' summary writing, *chains of reasoning* were observed, but the connections between concepts or ideas were not strong. Students did begin to compare multiple concepts and ideas, but these were not clearly linked together to synthesize scientific knowledge. Therefore, their writing seemed to display their ideas separately, and not to fully consolidate their ideas into a united story. In the previous study that examined students' writing samples when immersed in an argument-based inquiry approach under a teacher who is ranked as a high-level implementer of the SWH approach, the findings revealed that students developed more advanced reasoning than that shown by the current participants. In the previous study, three fifth grade students' writing samples were closely examined to explore their development of understanding of Seasons. In a classroom, a teacher and students successfully created a learning environment in which students' active negotiations took place in small groups and whole class settings, and students were required to constantly use their science notebooks as a place to explore and critique their own ideas.

It is difficult to directly compare the two different contexts, but in the previous study, a *reasoning network* was observed in participants' writing samples. This *reasoning network* can be constituted by the synthesis among multiple concepts and ideas, which requires evaluation of multiple resources and ideas to build scientifically plausible explanations regarding natural phenomena. Table 5-1 shows the difference between the previous study and the current study in terms of the complexity of reasoning revealed in participants' writing. As is shown, the complexity of reasoning revealed in students' writing in this study did not fully develop. I argue that this influenced and was influenced by students; reduced engagement in the process of evaluation. Their lower engagement in evaluation also impacted their understanding of the topic, so that students seemed not to fully understand the subject matter related to ecosystems. In this regard, I argue that students' engagement in evaluation, the complexity of reasoning they built, and their understanding of the topic are closely related.

Table 5-1 Comparison of Complexity of Reasoning between Previous and Current Study

Phase	Complexity of Reasoning	<u>Previous Study</u> High-implementer of the SWH approach	<u>Current Study</u> Low-implementer of the SWH approach
Fuzzy Understanding	Developing *Single Reasoning*	○	○
Seeking Alternatives	*Single Reasoning*	○	○
Comparing Ideas	Developing *Chain of Reasoning*	○	○
Consolidating Ideas	*Chain of Reasoning*	○	△
Further Negotiation	Developing *Reasoning Network*	○	X
	Reasoning Network	△	X

Note. The circle indicates all features of each phase and complexity of reasoning are evident in all students' writing samples, the triangle indicates that some features are observed in some students' writing samples, the X indicates that no features are observed in any students' writing samples.

Use of Sources, Evaluation, and Understanding

Students' use of sources for making meanings changed over time depending upon context. However, the general pattern observed in this study was that students gradually used fewer intuitive sources of meaning to build their ideas through writing. According to Klein, students start to build their understanding upon their use of narrative and contextualized language. Differing from the nature of students' expressive language, however, the feature of scientific language is the decontextualized and denotative nature of written argument. This distinctive difference also influences and is influenced by differences between the human cognitive architecture (an example of the second generation of cognition) and scientific knowledge (an example of the first generation of cognition). Drawing from the second generation perspective of cognition, students build scientific concepts based upon their fuzzy and contextual understandings. Since these fuzzy and contextual understandings are constituted by their perceptually driven reasoning, students tend to use more of their own language, which is narrative, metaphoric, and intuitive. From this perspective, in this study students tended to use more intuitive sources in the early phases when they built ideas through writing.

However, when students started to generate their own explanations through writing, a decrease in the use of intuitive sources in their texts was observed. This result can be interpreted in terms of the nature of scientific knowledge and texts. Scientific knowledge is represented by formal reasoning, and this reasoning is constructed by scientific language. Because, in scientific texts, multiple ideas and concepts are interconnected and interlocked by technical terminologies, representing the scientific reasoning or cognition underlying scientific texts requires the use of more condensed language; therefore less perceptual, contextualized, and intuitive language, but more denotative, decontextualized, and reflective language was observed over time.

However, this does not imply that students need to learn only scientific language or technical terminologies for the development of understanding. As one of the shifts Klein highlighted, students need to experience and practice a student-directed shift in using language to build their scientific knowledge. In other words, students build their understanding by using their perceptual, contextualized, and even intuitive language in the beginning. However, they will later face some demands to use more condensed and structured language to present and represent their developed and sophisticated understanding, which involves more complicated reasoning. Additionally, differing from talking, writing itself involves reflective processes (Galbraith, 2009), and students continually encounter more opportunities to engage in the evaluation process for choosing, organizing, and revising linguistic resources for presenting and representing their understanding through writing. From these points, exploring students' use of sources for making meanings helped to elucidate not only how students engage in type 2 processing, but also how they develop their understanding. Reversely, increased students' engagement in type 2 processing resulted not only in increased scrutiny of individual understanding, but also in decreased use of intuitive sources for making meaning through writing.

In this study, students' use of sources changed based upon contexts. Interestingly, students used many fewer intuitive sources for making meanings when many new linguistic resources were provided by other means such as teacher reading and watching videos. However, despite the increases in linguistic resources, students used limited cognitive and linguistic resources to build their ideas. Moreover, the complexity of reasoning did not change even though many linguistic resources were imported. The increase of linguistic resources was not thus automatically linked to the development of understanding. Furthermore, it was not linked to students' engagement in type 2 processing. Although Klein did not explicitly discuss the relationship among the three shifts, this finding suggests that obtaining only one shift cannot lead to the other two shifts. Simply speaking, achieving a single shift, for example students' use of the formal language of science in writing or talking, cannot help them construct scientific knowledge or scientific reasoning. Therefore, it can be argued that these three shifts should be mediated or negotiated at the same or a similar time.

The previous research also found that there was a similar tendency to develop reasoning and use of language (see figure 5-1). Compared to the results of the previous study, students' use of reflective sources was generally observed relatively less, and similarly students' complexity of reasoning was relatively less developed. However, students should experience and practice these three student-centered shifts not separately, but together.

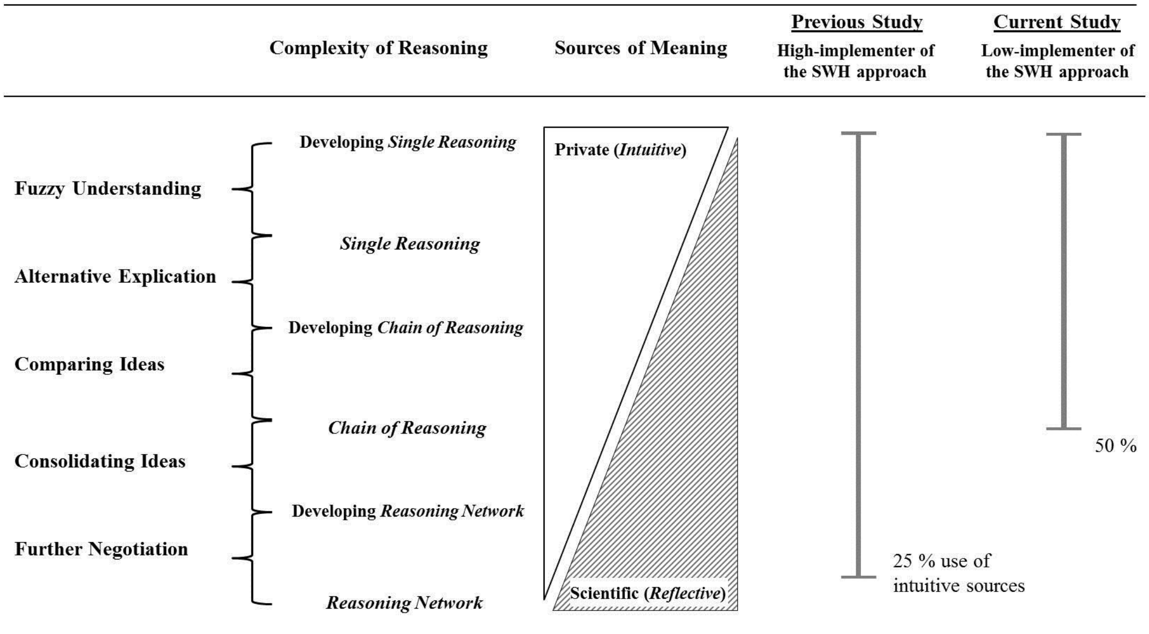


Figure 5-1 Changes in students' use of sources for making meaning: Comparisons to the Complexity of Reasoning and Previous/Current Study

Talking, Evaluation, and Understanding

The goal of exploring students' talking was not only to study how fifth grade students make meanings while engaging in public negotiation, but also to gain insight into how students develop their understanding through writing, since talking plays a different role in the development of students' cognition (Rivard & Straw, 2000). The findings of exploring students' engagement in public negotiation indicated that they had limited opportunities and demands to participate in the evaluating process not only for the development of understanding, but also for performing the roles of both critiquer and constructor. Since the teacher implemented the SWH approach, which emphasized public negotiation, students in this study were immersed in a learning environment in which their engagement in talking was strongly encouraged. However, in this study, dialogical interactions between the teacher and students as well as between peers focused more on sharing ideas or articulating information, rather than on developing ideas through elaborating, challenging, and especially evaluating ideas.

According to the argumentative theory of reasoning, Mercier and Landemore (2010) state that when diverse opinions are discussed, group reasoning will outperform individual reasoning. However, students in this study engaged in limited public negotiation for the development of reasoning, even though some individual students started to build their own alternative explanations beyond their initial inferences, and to compare multiple ideas through writing as private negotiation (individual reasoning). In other words, students' engagement in public negotiation (group reasoning) did not effectively help to enhance each individual's reasoning as it emerged in writing. Interestingly, Mercier and Sperber (2011) state that poor performance in standard reasoning tasks is explained by a lack of argumentative context. They continue to argue that when the same problems are placed in a proper argumentative setting, people turn out to be skilled arguers. They thus accentuate the context or learning environment in which students engage or are immersed. Similarly, the findings of the current study related to students' talking also highlight the learning environment as a critical component that both fosters the reasoning necessary for the development of student cognition and provides opportunities for students to experience and practice the process of construction and critique that helps them to grasp scientific practice.

However, findings of this study indicated that the learning environment in which students had engaged provided limited public negotiation for the development of reasoning. Evans (2006) maintains that there are three factors that influence the likelihood of the emergence of the process of evaluation (type 2 processing) when student reason. These three factors are: a) cognitive ability, b) instruction, and c) time. Among these three, I focused on the factor of instruction. Instruction can be associated with the learning environment since the teacher as a participant largely contributes to creating and developing that environment. Importantly, when comparing two different classrooms—

in the previous study, one with a teacher who is a high implementer of the SWH approach, and in the current study one with a teacher who is a low implementer of the SWH approach—no significant differences were identified in terms of the other two factors: a) students' initial cognitive ability measured by CCT, and b) average time students spent on public negotiation. In the previous study, the average student CCT score at the beginning of the academic year was 39.3, and it was 38.5 in the current study. Additionally, students in both classes spent most of their time engaging in talking in science lessons.

Although this study did not aim to explore the differences between the two studies, findings suggest that differently shaped and developed learning environments strongly influence students' development of understanding (presented in table 5-1 and figure 5-1). In conclusion, the teacher and students in this study engaged in limited public negotiation, which focused more on articulating than on evaluating ideas. Based on this finding, I argue that the limited public negotiation that was represented by the dialogical patterns in this study cannot support the development of understanding through writing or the practice of the roles of constructor and critiquer, which play a core function in the comprehension of scientific practice.

Discourse Space and Understanding Teaching and Learning

The mind is not a vessel that needs filling, but wood that needs igniting.
Plutarch's "Essays" (as translated by Robin Waterfield, 1992, p.50)

In this study, I have proposed a concept of Discourse Space to attain a better understanding of the ways in which students develop their cognition and enhance their awareness of scientific practice by using language. Based on my findings and discussion, this new concept raises several critical issues for the understanding of learning and teaching which can be linked to implications for teacher education. In this section, I briefly review the concept of Discourse Space and discuss this concept in relation to the findings of this study.

The model of Discourse Space proposed by this study consists of physical (time), cognitive, and linguistic resources that participants in discourse create, share, and develop, and is usually represented by language. Since I view language as a representational and epistemic tool, Discourse Space can be also investigated via these two aspects. For example, resources in Discourse Space portray not only the culture of classrooms, but also the experience, understanding, and identities of students while they attempt to become full participants in the discourse. Additionally, resources in Discourse Space help students epistemologically build experience, knowledge, identity, and the discourse of science when they engage in scientific practices.

Discourse Space is a space that participants in discourse create and share. In this study, drawing from Bernstein (1999), the researcher discussed the development of Discourse Space in two ways: a) horizontal development and b) vertical development. Bernstein stated that horizontal discourse is contextualized, segmentally organized, and localized, while vertical discourse is the form of a coherent, explicit, and systematically principled structure, and is hierarchically organized. From this point, it can be argued that since scientific discourse takes the form of a series of specialized modes of interrogation and specialized criteria for the production and circulation of texts, students need to cultivate their vertically-developed discourse, which can be considered the Discourse of science.

However, this does not mean that Discourse Space needs to be only vertically developed. Similar to the relationship between type 1 and type 2 processing, both horizontal and vertical development are necessary for students to be literate in the Discourse of science. Therefore, it is difficult to expect the vertical development of Discourse Space without its simultaneous horizontal development. In other words, the horizontally developed Discourse Space serves to expand the space to create and share resources that students can use for the development of understanding. These expanded resources need to be elaborated and evaluated by students, so as to develop the Discourse Space vertically, which is close to a form of scientific knowledge.

In this study, the development of Discourse Space over time was explored. Discourse Space that emerged in students' writing had developed from the expansion of the horizontal Discourse Space to the development of the vertical Discourse Space. This change indicates that students had engaged more in type 2 processing in order to present and represent their ideas through writing. This finding can be linked to students' engagement in talking throughout the unit. In science classes, the teacher usually opened a space for students' engagement in talking. Students had ample time to express, discuss, and argue their own ideas, but usually this dialogical interaction was framed by the teacher. Interestingly, the teacher used class reading and watching videos as one of her instructional strategies to help direct student understanding of the big ideas of the unit, but, in most cases, she focused more on articulating utterances and factual knowledge, rather than on elaborating or challenging students' understanding. Even in group presentations, despite students' active engagement in discussion, not many evaluating processes such as challenging and critiquing appeared. As a result of these activities, the expansion of horizontal Discourse Space was observed, but the development of vertical Discourse Space was not fully optimized. Therefore, as the mind is not a vessel that needs filling, but wood that needs igniting, Discourse Space can also be understood as the space students need to further develop through engagement in evaluation of diverse resources that emerge in the space. In other words, students as participants in discourse need to actively engage in discourse not only to share and create resources, but also to elaborate, evaluate, and synthesize those resources for the development of understanding, which can help them to become literate in the Discourse of science.

Implications for Teacher Education

I summarize five educational implications based on the findings and discussion. The implications that teacher education needs to thoughtfully consider are: (1) students' engagement in the process of evaluation is important not only for the development of understanding, but also for the opportunities it presents to perform the roles of both constructor and critiquer, (2) simply introducing scientific terminology and knowledge does not automatically lead to student learning, (3) three student-centered shifts in terms of reasoning, use of language, and knowledge construction should be encouraged at the same or a similar time, (4) writing as an argumentative activity can serve a mediating or negotiating role for these three shifts, so as to encourage or foster students' engagement in the process of evaluation or critique, and (5) the learning environment in which the teacher and students create and develop needs to provide not only opportunities but also demands for students to engage in both constructing and critiquing ideas.

First, this study emphasizes students' engagement in the process of evaluation. The development of complexity of reasoning that emerged in students' writing indicated the development of their understanding. This development was not influenced simply by students' participation in an inquiry approach that stressed their active engagement in learning, an approach which in some ways parallels the process by which scientists construct knowledge. Rather, this study found that students needed to learn not only how to play the role of constructor, but also how to play the role of critiquer in the community in order to grasp scientific practice, and that their engagement in the process of evaluation helped them not only to develop their understanding, but also to perform both roles. Therefore, for teachers, these findings suggest that students need to have more opportunities and demands to engage in the process of evaluation (or critique), as well as in construction.

Second, this study illustrated that the increase of linguistic resources was not automatically linked to the development of understanding. Students used many fewer intuitive sources for making meanings when many new linguistic resources were provided by other means such as teacher reading and watching videos. However, despite the increases in linguistic resources, students used limited cognitive and linguistic resources to build their ideas. Moreover, the complexity of reasoning did not change even though many linguistic resources were imported. The findings thus suggest that simply introducing scientific terminology and knowledge does not automatically lead to student learning. Therefore, teachers need to be aware that students need more than the simple transmission of scientific knowledge and language by a teacher.

Third, this study re-highlighted the three shifts suggested by Klein, and emphasized that these three shifts should be student-centered and encouraged at the same or a similar time. Klein introduced the shifts as what students need to go through in order to improve both fundamental and derived senses of scientific literacy. Findings from this study supported this perspective, and further suggested that students should take the lead on these shifts, and thatt obtaining only one shift does not lead to the other two shifts. For teachers, this finding suggests that students should experience and practice these three student-centered shifts not separately, but together.

Fourth, this study viewed writing as an argumentative activity and supported the perspective that writing can serve a mediating or negotiating role for the three shifts. Fundamentally, this study viewed writing as the creation of texts that explore relationships among ideas. In this study, students practiced and experienced the process of evaluation through writing as a reflective activity. Findings illustrated that students' limited engagement in public negotiation did not effectively enhance each individual's reasoning capacity; however, students' engagement in writing as private negotiation did help the development of their understanding over time. Therefore, for teachers, this finding suggests that students need to engage in writing not only as argumentative practice, but also as scientific practice so as to encourage and foster engagement in the process of evaluation not only for the development of understanding, but also for performing both the roles of constructor and critiquer.

Finally, this study underlined the importance of the learning environment. Findings illustrated how the teacher and students created and developed the learning environment through talking. This study emphasized the need to provide not only opportunities but also demands for students to engage in both constructing and critiquing ideas. The teacher-directed public negotiation did not help students develop ideas and use resources that emerged in discourse. Therefore, this finding suggests that teachers, as participants in creating and developing the learning environment, need to consider how to provide not only opportunities but also demands for students to engage in both constructing and critiquing ideas.

Implications for Future Research

This study explored students' use of language to investigate how they develop understanding through writing by examining the reasoning and use of sources that emerged in their writing samples; it also explored how students make meanings through talking by examining dialogical patterns between the teacher and students. In addition, this study proposed a concept of Discourse Space, and investigated the Discourse Space development that emerged over time in students' use of written and spoken language. Based on the findings, this study raises some questions and issues that require further research to help educators and researchers better understand the development of students' cognition through language use and how to encourage them to perform both the roles of constructor and critiquer in order to obtain a better grasp of scientific practice.

First, this study was conducted with a fifth-grade science teacher who utilized an argument-based inquiry approach for teaching and learning science, namely the SWH approach. Her teaching was assessed at a low level of implementation based on her RTOP score. In the previous study, I explored students' use of language when they were immersed in an argument-based inquiry approach under a teacher who is ranked as a high-level implementer of the SWH approach. Therefore, it is not known how the results of this study would look with other teachers, for example, those who are ranked as middle-level implementers of the SWH approach. Additionally, considering the SWH as one approach to argument-based inquiry, transferring this study to teachers who employ another approach to argument-based inquiry or who are inexperienced with either the SWH or another approach or teach in different grades could provide additional insights for the science education community.

Second, to deepen our understanding of the development of cognition through writing, this particular study designed a way to explore the complexity of reasoning and students' use of sources for making meaning that emerged in their written texts. Drawing from dual-processing theory, this method helped to explore how students perform both the roles of constructor and critiquer in order to grasp scientific practice. However, it is unclear how the development of student cognition influences performance of the two roles, or vice versa. Therefore, exploring this relationship raised by this study could provide insight into the development of students' understanding and their grasp of scientific practice.

Third, this study focused primarily on students' writing. Although it explored dialogical patterns created and developed by the teacher and students through public negotiation in order to understand the process of making meanings, this study limitedly explored the relationship between the two different negotiations for the development of understanding and the grasp of scientific practice. Additionally, this study did not explore students' reading, which could be seen as one of the fundamental language practices in the doing and learning of science. Therefore, exploring the relationships among the three different modes of language practice could provide insight into the ways in which students develop their understanding and comprehend scientific practice though talking, reading, and writing.

Fourth, this study explored students' use of language throughout a unit on ecosystems (9 weeks). Examining students' writing samples, field notes, informal conversations, observations, and other secondary data helped to deepen the understanding of students' use of language, their development of cognition, and their grasp of scientific practice. Observing the same and different level implementers' classes over an entire year of instruction, as well as their preparation before beginning a new academic year, might provide more substantive insights into any changes in the patterns of the three shifts their students experienced or practiced and into any changes in the role of teachers in these three shifts.

Fifth, this study proposed a concept of Discourse Space. Drawing from cognitive psychology and linguistics, this concept helped to forge a better understanding of in what ways students' use of language (the fundamental sense of scientific literacy) can promote their understanding of natural phenomena and their grasp of scientific practice (the derived sense of scientific literacy). Dual processing theory, which was used as a foundational theory to create and support this concept, suggested in what ways students' engagement in the process of evaluation could help to empower them to become literate in the Discourse of Science. However, it is unclear whether this concept can be transferred to different contexts and different disciplines. Therefore, there is a need for more theoretical and empirical studies to explore teaching and learning through this concept.

Limitations of the Study

Within this study, findings and important implications for elementary science teaching and science teacher education are presented and discussed. However, this study also had a number of limitations. First, it was limited in its relatively small sample size and focus on one classroom setting. Second, this study only examined students' use of language as it occurred during the first unit of science lessons. Third, the process of data analysis was limited by its complicated and time-intensive procedure. Finally, the theoretical foundation employed for this study was limited in an initial state of development.

The first limitation was that this study utilized a small sample size to explore students' use of language. Only six fifth grade students were purposefully selected and their writing samples were examined to investigate the development of their understanding through writing. During this unit, each student produced an average of 36writing samples, and a total of 216 of these samples were examined even though only a few samples were introduced and presented in the findings. Selecting a greater number of participants might help to more broadly represent other participating students' cognitive development through writing. Additionally, this study explored only one particular classroom setting. By comparing findings from the previous study, this study attempted to provide a better understanding of students' development of cognition through writing. However, exploring the same research questions in diverse classroom settings could help to obtain a fuller picture of this development, and could provide further insights into teacher education.

The second limitation was that this study explored 9 weeks of student learning and examined students' use of language as it occurred only during the first unit. Since the teacher had limited experience with the SWH approach, she and her students might have needed more time to become comfortable and familiar with using an argument-based inquiry approach in their science lessons. In addition, because the SWH approach emphasizes dialogical interactions and writing, the teacher might have more frequently played the roles of director or guider, and students might have had difficulty explicitly sharing and developing their own ideas. However, looking at the first unit did provide crucial clues that helped to illustrate how the teacher and students set up rules for writing, talking, and reading, and how the learning environment was initially created and developed.

The third limitation was that the process of data analysis was complicated and time-intensive. This process was grounded in cognitive psychology and linguistics, and was developed from data and multiple colleagues' critical reviews. The analysis was intended to deepen the understanding of students' use of language beyond counting words or frequency as a superficial and surface level of analysis. However, using this system required several rounds of practice and discussion, so that relatively limited sample sizes were used for this study.

Finally, the theoretical foundation employed for this study is limited in an initial state of development. This study was rooted in dual processing theory and proposed a new concept of Discourse Space. Additionally, Klein's perspective of scientific literacy was largely employed. Despite several attempts to adopt ideas and theory originating from cognitive psychology and linguistics, this area is still developing in science education. With this in mind, the theoretical foundation employed for this study might be described as being in a state of development. However, this attempt could contribute to expanding and developing the area of science education, and could provide novel insights into teacher education.

APPENDIX A

A MATRIX OF MODIFIED RTOP DEVELOPED BY THE SWH RESEARCH TEAM

(NOT PUBLISHED)

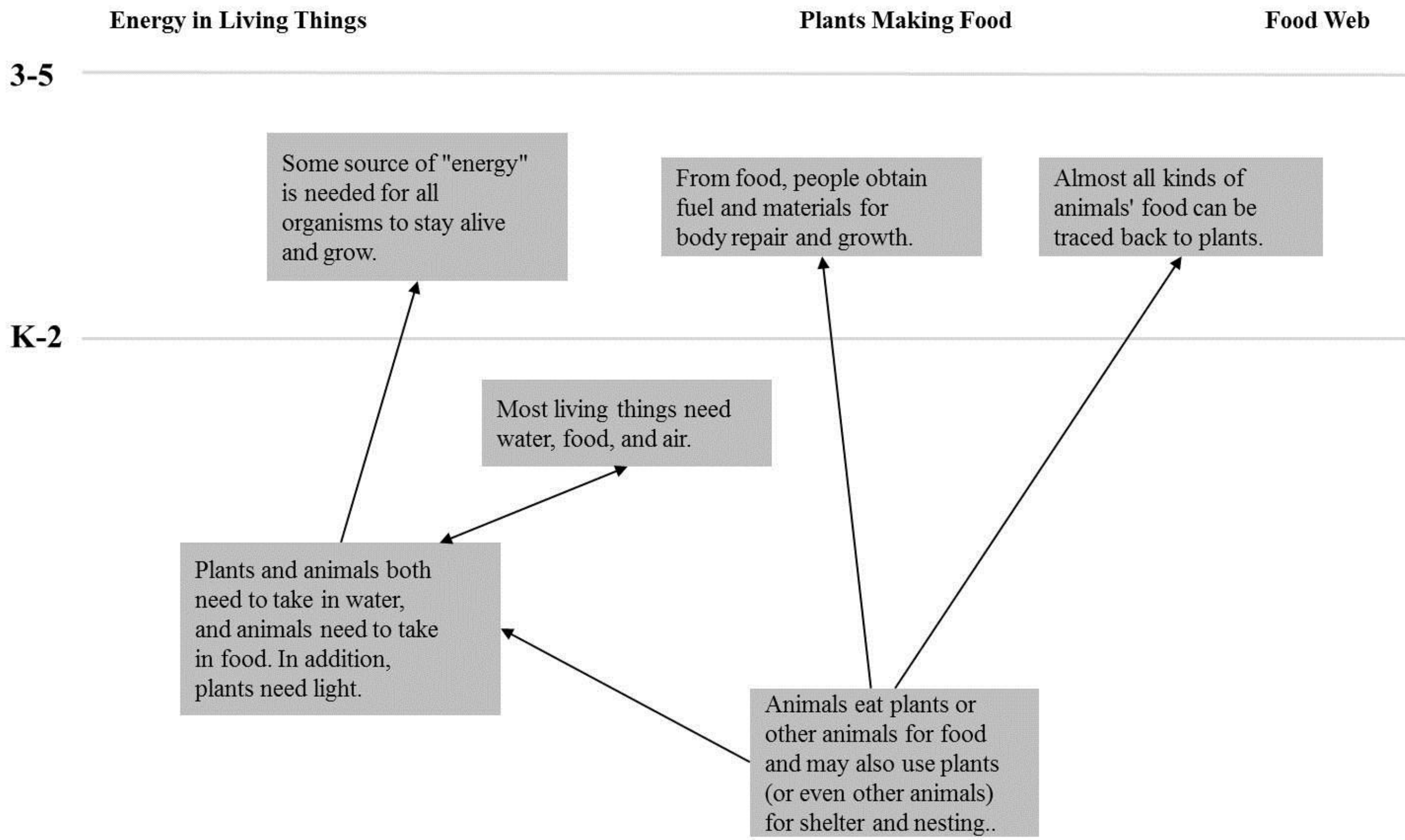
	No Implementation	Low Implementation	Mid Implementation	High Implementation
Students' Voice	• Instruction disconnected from students' prior knowledge • Student talk does not contribute to instruction	• Student talk is a small proportion of classroom talk; little or no student-student discussion occurs • Instruction has a few connections to students' prior knowledge • Students use one or limited methods to share ideas	• Some ideas that drive discussion come from students • Student-student discussion and argument emerge as meaningful components of the classroom • Students use multiple means to share ideas • Students and teacher begin to share discourse space	• Instruction is designed around student's prior knowledge • Student ideas direct and motivate the classroom • A high proportion of student talk occurs, with significantly developed student-student argument including challenges and rebuttals • Students regularly utilize multimodal representation to communicate ideas
Teacher's Role	• Gives information; very teacher directed • Teacher does not recognize student voice	• Attempts to incorporate more questions and time for students to talk, yet there is little to no connection of students' ideas to lesson • Teacher's ideas are still the focus of the lesson	• Works toward posing questions, challenging ideas and 'just-in-time' instruction; success is inconsistent • Misses key opportunities to guide students' ideas and enhance learning • Often falls back into "telling" mode; or provides less space for negotiating ideas	• Poses questions and guides discussion towards students' interaction and development of ideas • 'Wait time' gives students space to respond • Keeps students' ideas and flow of the lesson moving forward
Problem Solving and Reasoning	• Direct instruction from teacher • No student discussion or questioning	• Teacher questions students on information given • Limited discussions • Students do not present alternative ideas • Little to no evidence of critique/questioning	• Some small group and whole class discussion • Students question with some prompting • Teacher allows students to critique/question each other • Discussions may stall with long periods of silence or confusion	• Smooth rotations from small group to whole class discussions • Students question and critique each other openly • Development of alternatives/interpretations are encouraged • Teacher moves discussions along with appropriate questioning or examples • Teacher incorporates students ideas and understandings immediately in discussions
Questions	• No teacher questioning	• Teacher is directly answering any question. • Teachers give student wrong or right answer • Teachers asked more factual question • Teacher uses IRE (initiate, respond, evaluate) pattern of questioning	• Teacher does not directly answer the student with a correct/incorrect version. • Teacher asks more open-ended questions. • Teachers asked some thoughtful, higher-order thinking question • Teacher's questions focused on teacher–student interaction rather than to promote student-to-student discussion	• Teacher asks many layered questions to trigger divergent modes of thinking and adjusts levels to individual students. • By teacher's questioning, Students are asked to explain and challenge each other's response rather than teacher passing judgments. • Teachers encourage the continued multi-person conversation among students through many layered questioning.

APPENDIX B

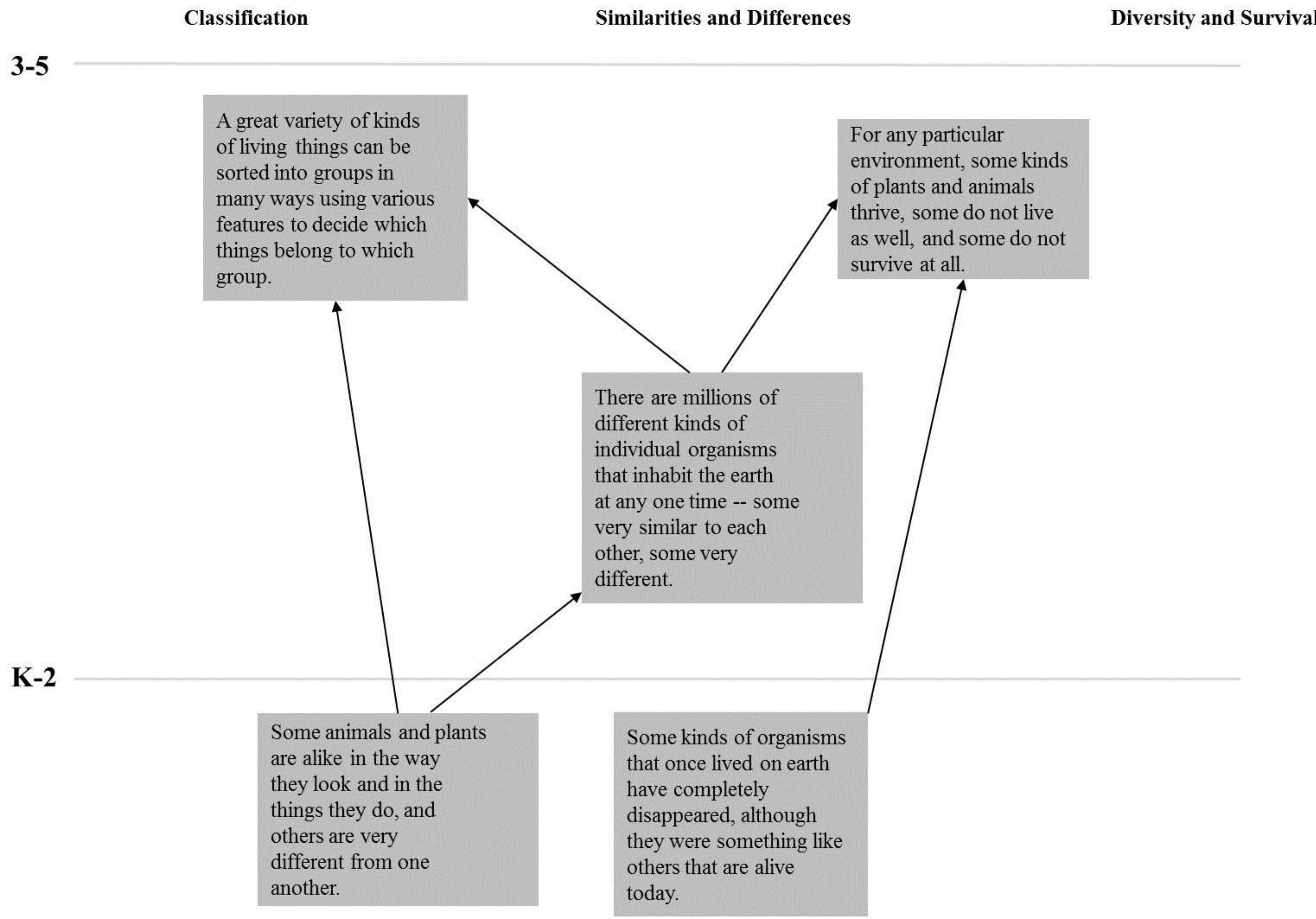
RELATED CONCEPT MAPS OF THE UNIT

(Sources from Science Literacy Maps, which National Science Digital Literacy distributed)

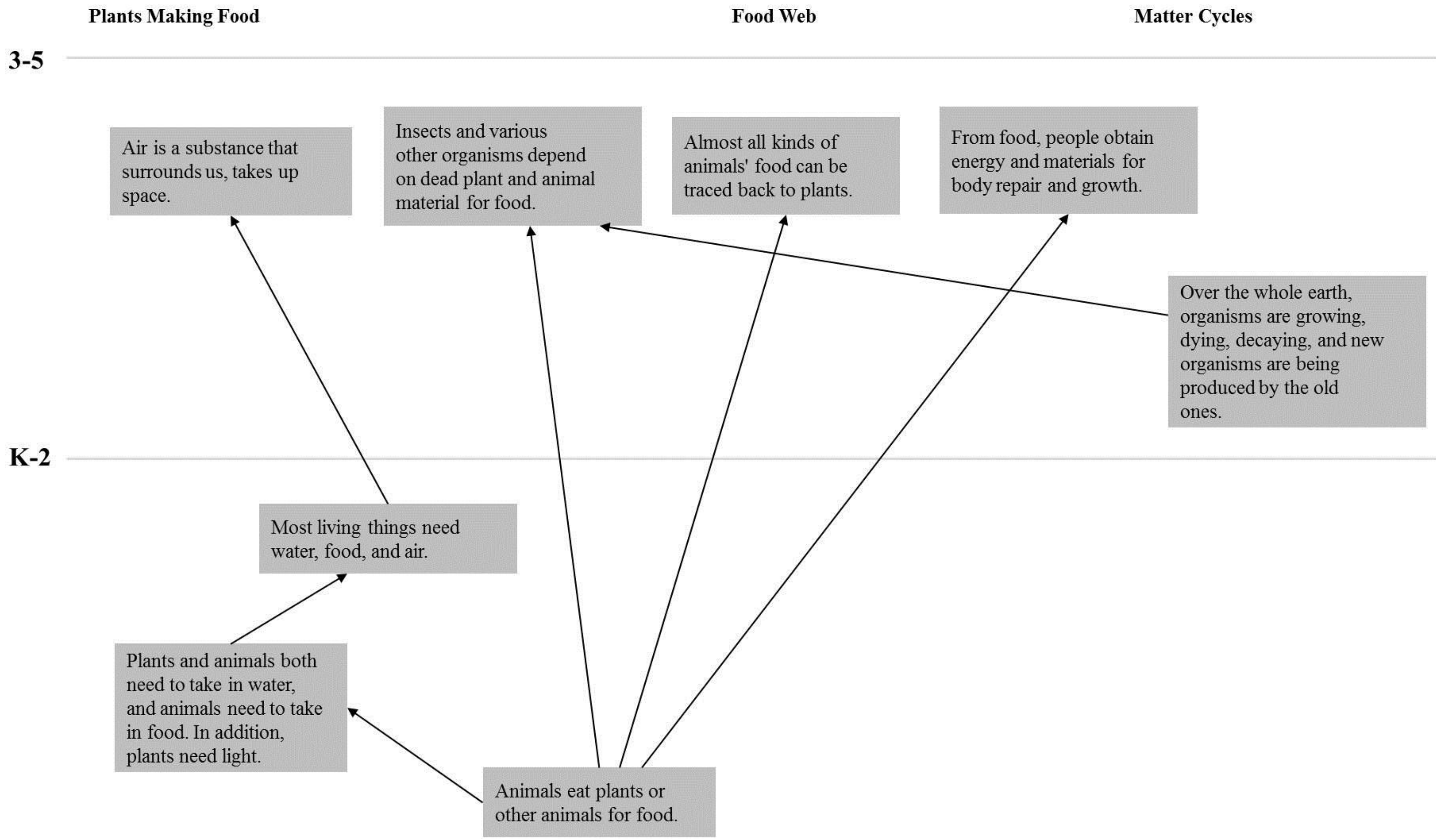
1. Big ideas related to concepts of energy in living things, plants making food, and food web



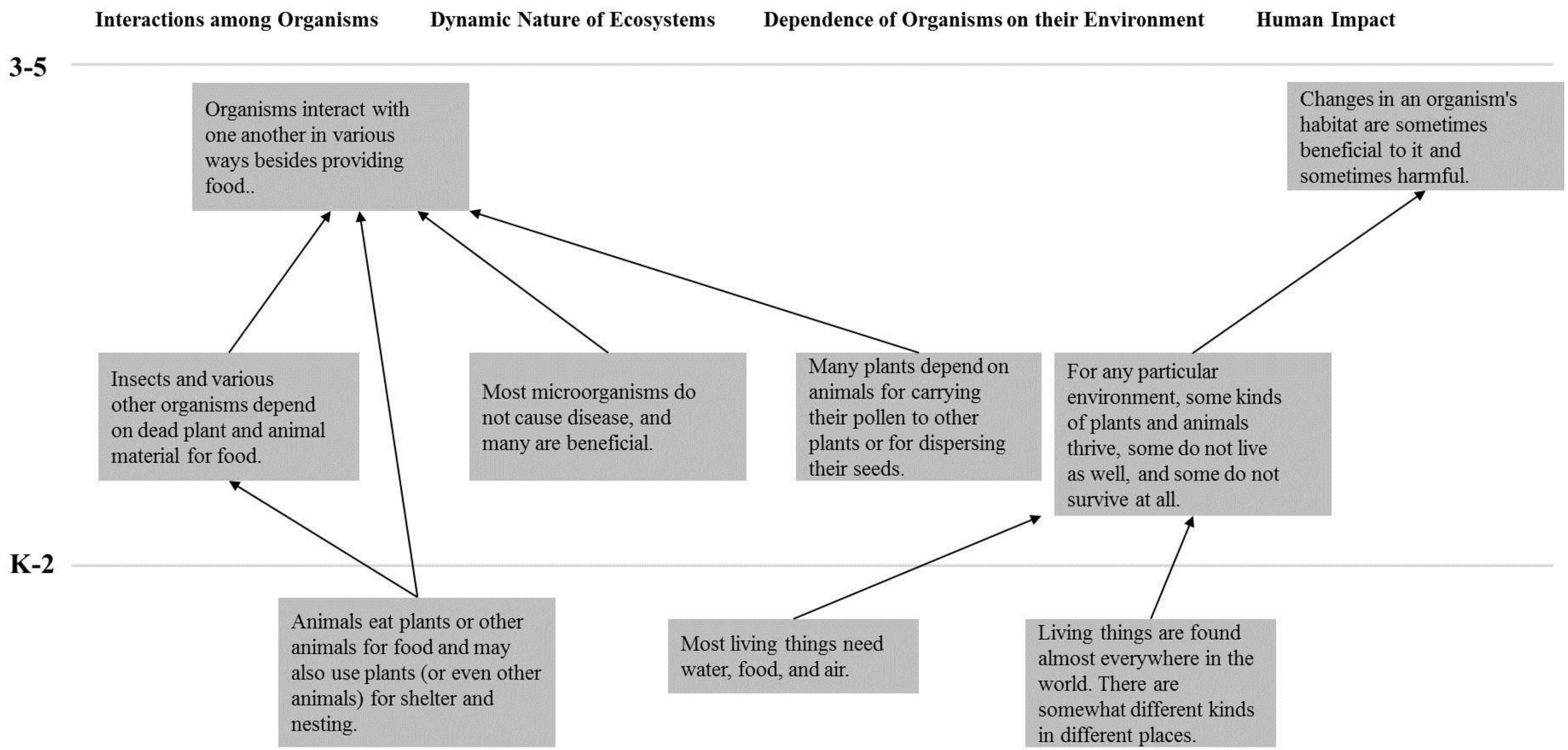
2. Big ideas related to concepts of classification, similarities and differences, and diversity and survival



3. Big ideas related to concepts of plants making food, food web, and matter cycles



4. Big ideas related to concepts of interactions among organisms, dynamic nature of ecosystem, dependence of organisms on their environment, and human impact



APPENDIX C

A MATRIX FOR EXAMING STUDENTS' FIRST WRITING SAMPLES

Category	Description	
Effective Organization	There may be strong story line throughout writing, and this story may be intimately connected to one another.	3
	There may be story line throughout writing, but it may be unclear to link each other.	2
	Students may only turn inward for the content of their writing, and this content may be positioned separately.	1
Sentence Fluency	The writing may use modal verbs (e.g., “might”, “should”) Generally, sentences may be completed, and students may not rely on using single sentence. Each sentence may be intimately connected one another, and they consists of a complete paragraph successfully. Texts include varied and complex sentence structures and/or sentence types appropriated to the writing purpose.	3
	Sentences are mainly single and compound. Students may sometimes try to expand texts by using complex sentence structure. Some sentences may be somewhat uncompleted, but sentences consist of one paragraph which has the same theme in spite of the lack of strong relationship between each sentence.	2
	Sentences are dominantly single. Sentences may be uncompleted, and there may be weak relationship between prior sentence and next.	1
Appropriate Vocabulary and Conventions	Contractions are used appropriately. The writing shows evidence of general accuracy in terms of grammar, spelling, punctuation, and capitalization.	3
	Many high-frequency words are spelt correctly, but there may be intrusive errors. Writing may show some awareness of additional punctuation features and control over full stops.	2
	Most words are high frequency, and there is little topic-specific vocabulary. Students may make many mistakes in terms of grammar, spelling, punctuation, and capitalization.	1

APPENDIX D

OBSERVATION PROTOCOL AND CODEBOOK FOR OBSERVATION

<table>
<tr><td colspan="5">Date:</td></tr>
<tr><th>Time</th><th>Activity</th><th>Purpose</th><th>Engaged Materials</th><th>Comments</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Overall reflection:</td></tr>
</table>

PURPOSE	DESCRIPTION	EXAMPLE
Initiating ideas	The task offers opportunities for students to engage in generating or presenting their default ideas with respect to big idea.	A student engaged in concept mapping activity at the beginning of unit.
Sharing ideas	The task offers opportunities for students to engage in distributing and exchanging their current ideas with peers.	In small group, students were asked to share their personal concept maps.
Reflecting ideas	The task offers opportunities for students to engage in reviewing, reconstructing, reorganizing and reexamining ideas that they have constructed so far.	Students were asked to individually write down in their notebook about what they learned today science class.
Seeking information	The task offers opportunities for students to engage in gathering and searching information that they might use for helping their idea development based upon their interests, ability to The task offers opportunities for students to engage in use resources, and decision to prioritize a certain information	Students engaged in activity of reading books and searching internet to get information.
Evaluating ideas	The task offers opportunities for students to engage in challenging, analyzing, weighting or valuing ideas as a process of making chosen ideas by them more plausible or reasonable.	Students in a group discussed how evidences could support their claim.
Elaborating ideas	The task offers opportunities for students to engage in developing their ideas by applying, expanding, explicating, and intertwining the default ideas	Students were asked to write about how your ideas could help your community.
Exploring ideas	The task offers opportunities for students to engage in investigating potentially useful ideas based upon their interests, abilities to use resources, and decisions to prioritize a certain information	Students as a group tried to design their own experiment to test their initial ideas.

APPENDIX E

INTERVIEW QUESTIONS

I. LEARNING

1. How do students learn?
2. What about in terms of the brain and how it functions –how does learning occur?
3. Can you give an example of how this looks in your classroom?
4. In science class what is your role in the learning process, where do you fit in?
5. What are the similarities and differences of your role in science class to teaching another discipline?
6. As a teacher how do you know when your students are learning?
7. How do you believe students learn science best?

II. SCIENCE

1. How would you define science?
2. Is science different from other disciplines of inquiry (religion, philosophy, etc.)?
3. Is there a difference between scientific knowledge and opinion?
4. How is new knowledge constructed in the scientific community?
5. Compare and contrast the way scientists work and the way students learn science.
6. If no examples are provided ask, "Can you give me an example from your classroom?"
7. Of how my students work compared with scientists?
8. What role does evidence play in your classroom?
9. Can you give me an example of how evidence is used in your classroom?
10. A few minutes ago, I asked you to describe how knowledge is constructed in the science. When new knowledge is constructed in science, how does the knowledge become accepted by the scientific community?

III. PEDAGOGY

1. How do you determine what to teach?
2. What type of materials and activities do you use to support learning in your classroom?
3. Give me examples of what it looks like in your classroom when students are engaged in learning.
4. What does inquiry look like in your classroom?
5. How do you use questions in your classroom?
6. How do you decide what to ask your students?
7. What are your goals for teaching science?

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