Teachers’ Feedback to Foster Scientific Discourse in Connected Science Classrooms

DISSERTATION

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by

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Abstract

Science classroom discourse contributes in important ways to the development of students’ scientific understanding and reasoning skills. However, many science teachers are not ready for scientific discourse, given that much of their time is spent delivering scientific knowledge. A classroom dialogue should be differentiated from an argumentation or explanation because its fundamental purpose is to assist students to reach a certain point of understanding or learning.

Two purposes of this dissertation study have been accomplished. One is to develop a conceptual model that explains how scientific reasoning can be practiced through classroom discourse. Through the literature review, a conceptual model that encompasses the aspects of scientific reasoning and inquiry, formative feedback, and scientific discourse was developed. The other is to develop a Classroom Discourse Analytical Tool (CDAT) and to apply that tool to assess how a teacher leads her/his classroom discourse with scientific reasoning components.

The data used in this study are all classroom observation videos and the transcripts from five physical science teachers who completed the first year of the Classroom Connectivity in Promoting Mathematics and Science Achievement (CCMS) project. The results from the CDAT data analyses generated two models: one explains how teachers’ questions and feedback affect the classroom discourse, and the other identifies how the reasoning components utilize the discourse. In addition, the results
produced three representative and quantitative values: (1) Length of Dialogue (LOD), (2) number of Reasoning Components (#RC), and (3) Movements in Reasoning Components (MRC).

Several implications are suggested for the science teachers to support their scientific classroom discourse. First, subsidiary questions and elaborative feedback play a critical role in building a productive dialogue. Second, the use of reasoning components enhances subsidiary and feedback questions that increase students’ engagement in the classroom discourse. Third, the evaluative and corrective feedback usually terminates the discourse quickly. Therefore, using these types of feedback should either be carefully considered or avoided in many discourse situations. Lastly, in a dialogue or through dialogues, talking only about scientific knowledge (SK) does not engage the students in the classroom discourse.

The analysis with CDAT can potentially identify how educational interventions affect the classroom instructions/discourse. In this study, how the use of connected classroom technology (CCT) affects the teachers’ discourse has been examined. The CDAT analysis revealed how and what differences CCT can make in both the teacher’s discourse patterns and the characteristics of each classroom discourse. This study reveals that the use of CCT often increases students’ opportunities to talk (Chi-Square = 3.347, \( p = .06 \)), decreases teachers’ explanatory talk, and increases talk about scientific observation/data and patterns from data in their classroom discourse.

Interventions that support teachers to effectively use discursive dialogue with CDAT could be validated by examining the effects on students’ achievements and
cognitive development in future studies. Further research and professional development for secondary science teachers and pre-service teachers can be applied to improve the skills and understandings that will generate productive and scientific classroom discourse and enhance students’ scientific literacy and reasoning skills.
“The belief that all genuine education comes about through experience does not mean that all experiences are genuinely or equally educative”

John Dewey

I dedicate this study and document to all those who have shared the educative experiences with me, and most especially, to my family. All my moments with my wife YunJeung, my son YoungGun, and my daughters YoungHyun and YoungIn, are precious learning experiences for me in this life.
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PUBLICATIONS

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FIELDS OF STUDY

Major Field: Education
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Chapter 1 : Introduction

Background

Classroom discourse refers to language-in-use that teachers and students communicate with each other in the classroom (Cazden, 2001; Gee, 2010). As a scientific community, science classroom discourse needs to be coordinated to assist students’ scientific understanding and reasoning skills (Gee, 2004; Lemke, 1998; National Research Council, 2004). However, many science teachers are not ready for scientific discourse, given that much of their time is spent to deliver scientific knowledge; teachers do most of the talking and students are rarely asked to share their thinking (Duschl, Schweingruber, & Shouse, 2007; Hardy, Kloetzer, Moeller, & Sodian, 2010; Windschitl, Thompson, & Braaten, 2008). Some researchers say that the deficiency of productive discourse is caused by lack of knowledge of formative feedback (Black & Wiliam, 1998; Kluger & DeNisi, 1998; Shute, 2008), but others insist that it is because of lack of scientific reasoning skills and content knowledge (Hardy et al., 2010; Windschitl et al., 2008; Zimmerman, 2007). However, both would affect the classroom discourse and students’ science learning: formative feedback as a way of delivering feedback and scientific reasoning as the content to be delivered.

Scientific discourse demands teachers’ skill and persistence that help students close the gap between scientific reasoning and everyday reasoning; the former is based on evidence and rationale with a goal of shared understanding, and the latter relies on the
power of authority and experiences with a goal of winning (Duschl, 2008; Duschl et al., 2007; NRC, 2004, 2007). On the other hand, studies have shown that teachers’ feedback has effects (both positive and negative) on students’ learning science through classroom discourse (Black & Wiliam, 1998; Duschl et al., 2007; Kluger & DeNisi, 1996; Shute, 2008). Despite the demands for teachers’ reasoning and feedback skills, science teachers usually do not have the opportunities to improve their capacity for their classroom discourse that is teacher-dominated and intended to persuade students of the validity of the scientific knowledge (Black & Wiliam, 1998; Hicks, 1996; NRC, 2007).

The Board on Science Education (BOSE) emphasizes scientific proficiency as learning goals with main themes of scientific literacy and reasoning skills for students to reach to be considered fully proficient in science by participating in scientific practices and discourse (NRC, 2007). The National Science Education Standards (NSES) also emphasizes scientific discourse since everyone needs to use scientific information to make choices and to engage intelligently in public debates about important issues in their communities (NRC, 1996). As a scientific community, a science classroom must help students advance their understandings in scientific argumentations and explanations (NRC, 2007). Students come to school with powerful resources with which they explain natural phenomena, conduct investigations, and engage in argumentation with their own reasoning and knowledge acquired from various resources (Duschl, 2008; NRC, 2004). According to constructivists’ views, these knowledge resources should not be ignored but learning science should be constructed with these resources including their experiences. As a core goal of science education, the students’ ability in scientific discourse is associated with their reasoning skills in thinking deductively and inductively such as
selecting data as evidence, finding patterns from the data, and developing theories/models. Both scientific discourse and reasoning can be framed by the scientific inquiry process with its fundamental components of observation, data, patterns, and theories or models as well as its phases of observing, describing, comparing, analyzing, hypothesizing, designing, predicting, evaluating, theorizing, or generalizing (Duschl & Gitomer, 1997; Hardy et al., 2010; Lemke, 1998)

One major difficulty for teachers with implementing effective instructional discourse in their classrooms is interacting with a large number of students in a limited time. New advanced technologies can assist teachers in communicating with their students effectively to make students’ thinking visible, and to provide tailored feedback to meet specific student needs (NRC, 2004; Owens, Irving, Pape, Abrahamson, & Sanalan, 2007; Pape, Owens, & Irving, 2008; Roschelle, Penuel, & Abrahamson, 2004). One such system, called Classroom Connectivity Technology (CCT) consists of both hardware and software including students’ handheld devices like graphing calculators to “log on” to a classroom communication network that permits the instructor to send questions for students to work on and permits students to enter answers through their handheld devices (Owens et al., 2007; Roschelle et al., 2004). The core advantage of CCT is the information about how well the entire class understands concepts provided in a timely manner with appropriate format of data. With this accurate, just-in-time information, the teacher can modify the course of instruction to enhance students’ deep learning approaches and participation in the classroom discourse (Abrahamson, 2006; Stowell & Nelson, 2007).
**Statement of the Problem**

Students’ participation in scientific discourse can be both a goal and a method of science education. Therefore, classroom discourse has been a major research topic in science education for the last several decades along with formative assessment and feedback (Gee, 2010; Hattie & Timperley, 2007; Lemke, 1998; Shute, 2008; Windschitl et al., 2008). In classroom discourse, many studies have shown that teacher feedback has an evident effect on students’ learning science positively or even negatively (Duschl et al., 2007; Kluger & DeNisi, 1998; Kulhavy, White, Topp, Chan, & Adams, 1985; Shute, 2008). Although many researchers have studied students’ psychological changes such as motivation, efficacy, or self-regulation (Hattie & Timperley, 2007; Kulhavy et al., 1985; Shute, 2008), how teachers’ feedback works for students’ scientific reasoning skills has rarely been studied.

The role of teachers’ feedback in a science classroom should be considered as a critical element to enhance students’ scientific understanding and reasoning skills through the classroom discourse regardless of the type of lesson. Also, the use of educational technology should be considered not just as an efficient way of teaching, but also as an effective way to provide students and teachers with more opportunities for feedback, reflection, and revision (Irving, Sanalan, & Shirley, 2009; NRC, 2004; Owens et al., 2007). The environment with CCT makes it easy for students to be informed specifically about their learning status and other students’ and increases the opportunities for students to appreciate teachers’ timely feedback.
However, the studies of teachers’ feedback often focused only on general aspects of learning such as motivation, engagement, or metacognition, and not of specific aspects of learning science (Black & Wiliam, 1998; Hattie & Timperley, 2007; Kluger & DeNisi, 1998; NRC, 2004; Shute, 2008). Although the discourse studies have usually dealt with scientific reasoning and knowledge in science classrooms, they have not focused insightfully on how teachers’ questions and feedback supports the scientific discourse (Duschl & Gitomer, 1997; Nystrand & Gamoran, 1991; Webb, Nemer, & Ing, 2006; Windschitl et al., 2008). Studies of educational technology have focused on its integration and implementation to investigate how it facilitates teachers’ instruction and interaction with their students (NRC, 2006; NRC, 2004; Reay, Li, & Bao, 2008; Roschelle et al., 2004), while studies on CCT with particular foci on learning science and opportunities for teachers’ feedback have rarely been conducted.

**Purposes of the Study**

Through this dissertation study, a major purpose is development of a conceptual framework and analytical tool to assess how teachers’ feedback leads classroom discourse to be framed by scientific inquiry. The literature review of discourse, scientific discourse, scientific reasoning, teachers’ feedback, and educational technology will provide a theoretical framework combining all the features of them with bases of learning theories, methodologies and suggested pedagogical integrations. Through the literature review, an initial conceptual framework and a coding tool will be developed, and during the analysis of the data, they will be scrutinized and modified continually so that the result can be applied practically and empirically to other classroom observations.
The second purpose of this study is to examine how well the tool characterizes the science classroom discourse from teacher to teacher. The data analysis with the tool has two aspects: first, how teachers lead the classroom discourse with questioning and feedback; and second, how the teachers support scientific classroom discourse with the use of scientific reasoning components.

The third purpose of this study is to examine how CCT affects the classroom discourse through teachers’ questioning and feedback to support scientific classroom discourse. According to the literature, CCT as a tool for facilitating formative assessment and feedback has great potential to change classroom discourse (Pape et al., 2008; Shirley, 2009). Through the analysis of teachers’ feedback and the classroom discourse, the framework and tool have been continually tested and revised and additional statistical analyses will be conducted with the results from the analyses.

As a result of this study, diagnostic information for the teachers in shaping scientific discourse to guide teachers’ instruction will be produced. Since teachers and students’ conversation happens almost every day in their classrooms regardless of the types of lessons, well-prepared/practiced teachers’ feedback could have a huge effect on students’ scientific reasoning skills and learning science (Windschitl et al., 2008).

**Research Questions**

First, an analytical framework and tool for evaluating science classroom discourse and second, a valuable theoretical and empirical model of teachers’ formative feedback for scientific discourse to enhance students’ understanding and reasoning skills will be suggested as results of this study. Therefore, how teachers’ feedback leads classroom
discourse to be scientific based on scientific inquiry, how classroom discourse and teachers’ feedback can be assessed with the criteria of scientific standpoints, and how educational technology can be used for specifically learning science in a science classroom are the basis of this study.

In this study, with the classroom discourse analytical tool (CDAT), the following research questions are explored:

1. How does the analytical tool characterize the classroom discourse with teachers’ questioning and feedback?

2. How does the analytical tool identify how teachers promote scientific classroom discourse?

3. How does the analytical tool identify the differences in discourse between the classroom with CCT and without CCT?

**Significance of the Study**

The results from this study will assist a deeper understanding of how teachers’ feedback can be affected by the use of CCT and how teachers’ feedback forms a scientific discourse. Scientific inquiry is the most prevalent issue in science education for all grades and should be applied overall to the lessons in science classrooms. However, inquiry-based learning has usually focused on scientific practices such as hands-on experiments, problem solving activities, or collaborative projects focused on doing scientific activities. Many conversations between a teacher and his/her students occur in a classroom, and the teacher’s talk leads the discourse with powerful authority. Therefore,
information about how teachers lead the discourse to be scientific can be very useful in improving their instructional practice with questioning and feedback. This study’s results can help teachers evaluate their classroom talk to make informed decisions regarding instructional practices. If equipped with more accurate and descriptive diagnostic information about their discourse patterns, teachers could adapt the suggested models in this study for their instructions in ways that promote students’ science learning.

The features of CCT are facilitating collection, aggregation, and display of data concerning student understanding. Many studies revealed that the technology improves students’ achievement compared to control groups who did not use it (Caldwell, 2007; Irving et al., 2010; Pape et al., 2008). However, how CCT and the information are connected to teachers’ instruction and discourse in their classrooms need to be studied more. This dissertation study will examine how CCT facilitates the classroom discourse and teacher feedback.

This dissertation study goes beyond previous studies in several ways. First, this study makes connections between teachers’ feedback and scientific discourse to examine how each one supports the other in science classrooms. Many studies on teachers’ feedback have focused on mainly psychological aspects like motivation, engagement, or encouragement while this study explores a role of teachers’ feedback in leading classroom discourse in the specific context of science classrooms. Second, this study develops the ways of assessing how scientific the classroom discourse is by using scientific inquiry components. Many studies on scientific discourse have dealt with scientific understanding, scientific language, and scientific inquiry. This study will be
combining all the aspects by framing scientific reasoning and inquiry. The resulting information from the analysis with the tool will support teachers in leading scientific discourse and improving assessment and feedback skills.

Finally, the tool developed in this dissertation study produces descriptive and quantified data about science classroom discourse. Those data could be used for other studies and professional development in science education. They can be either dependent variables or independent variables for the studies. On the other hand, it provides sets of criteria for assessing how the teachers have improved in practice. Also, the quantified data transformed from the observation can make connections with other quantitative data sets to conduct various statistical computations such as correlations, ANOVA, or structural equation modeling.

**Definitions of Terms**

In this proposed study, several terminologies will be used continually so their meanings can be identified specifically. Some terms have broadened in meanings from the ones which are used in several other studies and others are narrowed for this study.

**Discourse**

In the Oxford English dictionary, *discourse* originated from Latin *discursus* which means “running to and from” and generally refers to “a. Process or faculty of reasoning as in the phrase discourse of reason, b. written or spoken treatment of a subject, in which it is handled or discussed at length” (Hawker, Soanes, & Waite, 2001). The word “discourse” may be interchanged with the word “discussion” or “conversation”, but
discourse is further facilitated by shared assumptions, cultural cues and values in the discourse communities (Gee, 2004).

**Scientific Discourse (SD)**

Scientific discourse is a communication that shares particular types of values and assumptions in the science community (Hackling, Smith, & Murcia, 2010; Lemke, 1998; Zwiers, 2007), which aligns with a style of language organized by scientists who tend to communicate in particular linguistic styles called “registers” (Hackling et al., 2010; Zwiers, 2007). Therefore, scientific discourse requires a unified set of words, symbols, and reasoning skills to construct and communicate a coherent interpretation of scientific knowledge (Gee, 2004; Hackling et al., 2010; Zwiers, 2007).

**Teacher Feedback (TF)**

Shute (2008) defined feedback as “information communicated to the learner to modify his or her thinking or behavior to improve learning.” Kluger (1998) also identified feedback as verbal or written actions by an external agent to provide an informational aspect of the learners’ task performance.

**Formative Feedback**

The main function of formative feedback is to make students be aware of the discrepancy between a student’s perceived status and actual current learning status (Kluger & DeNisi, 1998). After acknowledging the discrepancy, teachers’ feedback can lead the students to close the gap between the goal and current status, which means increasing students’ learning (Shute, 2008).
Scientific Reasoning (SR)

Scientific reasoning is the way that scientists make sense of the world by finding connections among observations, patterns, and theoretical models represented such as model-based reasoning or evidence-based reasoning. Observations or data used by scientists are from experiences that can be verified, reproduced, described, or measured precisely. Patterns in data such as laws, generalizations, graphs, and tables are ways of representing relationships that scientists see in the data and scientific models/theories are designed to explain patterns in data (Anderson, 2007).

Reasoning Components (RC)

Scientific inquiry typically indicates two aspects: one is the set of scientific behaviors cognitively and physically which includes observing, collecting, comparing, contrasting, analyzing, hypothesizing, theorizing, predicting, and etc. called phases of inquiry; the other is the set of components of inquiry that consists of observations/data (OD), patterns (PD), and theories/models (TM). Both are also used for scientific reasoning by connecting two aspects with the ways of scientific thinking, induction, deduction, and inference. Therefore, scientific reasoning also consists of phases of inquiry, components of inquiry, and ways of thinking. In this study, from the conceptual model, the components of scientific inquiry, students’ experience (EX), and scientific knowledge (SK) are grouped as reasoning components (RC).

Everyday Reasoning (EDR)

Everyday reasoning, compared to scientific reasoning, is usually based on experiences that allow people to make sense of the world with their personal experiences
and common knowledge. Everyday reasoning often tends to use informal metaphors or analogies that relate new experiences to familiar knowledge from previous experiences (Anderson, 2007).

**Classroom Connectivity Technology (CCT)**

CCT consists of both hardware and software including a student’s handheld device like a graphing calculator to “log on” to a classroom communication network that permits the instructor to send questions for students to work on and permits students to enter answers through their input device (Owens et al., 2007; Roschelle et al., 2004). Students’ answers can be displayed to the class anonymously with a form of histogram or displays that can be made of students’ individual work. Various data for each student’s response is stored and could be analyzed to help evaluate and revise the teachers’ instruction.
Chapter 2: Literature Review

The National Science Education Standards (NSES) identify scientific discourse as a goal and a method for learning science with the frame of scientific inquiry (NRC, 1996). Since students may engage in debates and may need to make choices in their everyday lives, the ability to think and decide rationally using scientific reasoning and information is one of the most critical goals in science education (NRC, 1996). The NSES teaching strands also recommend that science teachers support and focus on inquiry while interacting with students by leading scientific discourse (NRC, 1996).

In addition to scientific discourse, Taking Science to School (NRC, 2007) emphasizes harmonizing content knowledge and reasoning skills as goals of science education. Scientific discourse can be considered as ways of talking in a science community and the ways of talking are associated with ways of thinking that is scientific reasoning. Therefore, scientific discourse can be thought in the frame of scientific inquiry with scientific reasoning based on transformations of thinking among students’ experiences, observations/data, patterns, and theories/models (Duschl & Gitomer, 1997; Hardy et al., 2010). Furthermore, students’ scientific reasoning skills in developing of scientific explanations and generating scientific evidence can be also achieved by participating actively in scientific discourse (Duschl & Gitomer, 1997).

How teachers enhance students’ conceptual understanding and reasoning skills has been a major research topic for the last several decades aligned with various types of
discourse such as argumentation, explanation, or discussion as well as teachers’ prompts and questioning (Duschl, 2008; Duschl et al., 2007; Hardy et al., 2010; Shute, 2008; Windschitl et al., 2008). However, evaluation or investigation of scientific classroom discourse has been rarely studied with teachers’ use of feedback. Teachers’ feedback can have a critical role not only to shape productive classroom discourse by prompting and guiding their students’ engagement (Hardy et al., 2010; Kluger & DeNisi, 1996; Webb et al., 2006), but also to foster students’ reasoning skills by assisting them to use empirical evidence to support their claims (Duschl & Gitomer, 1997; Hardy et al., 2010; Windschitl et al., 2008). However, teachers’ feedback could also have negative effects on learning and performance in students’ learning by affecting students’ motivation and cognitive load (Hattie & Timperley, 2007; Kluger & DeNisi, 1998; Kulhavy et al., 1985; Shute, 2008). Most feedback studies have focused on students’ psychological changes such as motivation, efficacy, or self-regulation (Hattie & Timperley, 2007; Kulhavy et al., 1985; Shute, 2008) while how teachers’ feedback promote scientific discourse to enhance students’ reasoning skills has rarely been studied.

To enhance the opportunities for feedback, many research studies suggest various educational technologies. Especially clickers or classroom connectivity technology (CCT) allows students and teachers to communicate effectively and efficiently (NRC, 2004; Pape et al., 2008; Roschelle et al., 2004). Although interactive technologies cannot guarantee effective learning by themselves, many aspects of the technology make it easier to create constructive environments with the effective communication to continually assess students’ learning, refine students’ understanding, and build a sense of
community for learning (Abrahamson, 2006; NRC, 2004; Owens et al., 2007; Roschelle et al., 2004).

This chapter presents the literature on scientific discourse, scientific reasoning, formative feedback, and connected classroom technology. This review will explore how classroom discourse affects students’ learning, how scientific discourse is differentiated from other type of discourse, how teachers’ feedback can enhances students’ science earning. However, the main theme of this review is that these areas can support each other for students’ science learning. Therefore, through the literature review, how teachers’ formative feedback support scientific classroom discourse, how scientific reasoning can be utilize the classroom discourse, and how scientific discourse improve students’ scientific understanding and reasoning skills will be discussed. Finally, how CCT can facilitate teachers’ formative assessment and feedback in science classrooms will be discussed.

Part I. Classroom Discourse and Students’ Learning

Scientific Discourse: Specialized Discourse in Science

A science classroom is a discourse community sharing common understanding, assumptions, and ways of communication in their speaking and writing for learning science. When students come to the science classrooms, they already have much everyday experience and are used to everyday discourse, which needs to be coordinated with scientific discourse to assist scientific understanding (NRC, 2004). Students’ talk could be scientific discourse by presenting evidence or theories but it is also likely to be
everyday talk by presenting just facts, metaphors, experiences, beliefs, or vicarious authorities even in a science classroom. If teachers can scaffold students to identify a gap between their talk and scientific discourse, classroom discourse can improve students’ scientific understanding and reasoning skills as well (NRC, 2004).

Talking science does not simply mean talking about science but doing science through the medium of language (Lemke, 1998). When scientists talk or do science, it usually means observing, describing, comparing, classifying, analyzing, discussing, hypothesizing, theorizing, questioning, designing experiments, following procedures, judging, evaluating, deciding, concluding, generalizing, and etc. All those are regarded as phases of the scientific inquiry process and scientific reasoning methods. The learning levels in Bloom’s Taxonomy can be enhanced through scientific discourse since connecting components in scientific reasoning requires students to use all levels of cognitive thinking. Research studies in science education have a strong focus on activities, investigations, and materials that have a physical and concrete presence in the classroom. However, through classroom discourse, teachers and students are able to work on ideas and develop understandings. Activities provide experiences that give a purpose for discourse to support the development of students’ understanding and scientific literacy (Hackling et al., 2010).

As a certain way of mirroring science, the scientific ways of knowing, understanding, and reasoning can be practiced in a science classroom by transferring experiences to observations, metaphors to patterns or beliefs to theories. The science classroom discourse should not be just to acquire scientific knowledge or to build up an
authoritarian world picture (Duschl, 2008; NRC, 2004, 2007). Rather as a rationally enunciated structure of acceptable beliefs about the world surrounding themselves, it should be a process that students invent, criticize, and modify as they go along, so that it ends by being, as nearly as they can make it, a story about real life (NRC, 2004). The ways of discourse employed in science often differ from the ones allied with the language used in their everyday lives for engaging in arguments and evaluating evidence (NRC, 2007). A scientific community including a science classroom shares a unified set of words, symbols, and reasoning skills to construct and communicate a coherent interpretation of scientific knowledge (Gee, 2004; Zwiers, 2007).

From this standpoint of discourse, learning science should not be just accumulating scientific knowledge, but should also include the ability to engage in scientific discourse that fosters students’ ability to organize, develop, and evaluate knowledge corresponding to scientific standards (Windschitl et al., 2008). In science education, these views have led discourse studies to place a heavy emphasis on the process of scientific reasoning: (a) requiring data as evidence, (b) evaluating patterns for the data, (c) justifications for specific theories, and (d) examining methods for generating data (Duschl, 2008; Rosebery, Warren, & Conant, 1992; Van Zee & Minstrell, 1997). The results from the studies showed positive gains in learning as students become more actively engaged in the classroom discourse by making students’ thinking more visible to both the teacher and the students (Duschl, 2008; Hardy et al., 2010; Nystrand & Gamoran, 1991). In addition to the thinking aloud, an appropriate practice of listening to scientific talk of clarifying evidence, defending claims, and coordinating scientific knowledge can
also help in fostering productive scientific discourse (Hackling et al., 2010; Herrenkohl & Guerra, 1998; Hicks, 1996; Van Zee & Minstrell, 1997).

**Teacher-Dominated Classroom Discourse**

Studies have reported that many science teachers are not ready for the scientific discourse given in the contexts wherein much of their time is spent to mediate conflicting students’ world views and teachers do most of the talking and students are rarely asked to share their thinking (Duschl & Gitomer, 1997; Duschl et al., 2007; Hardy et al., 2010; NRC, 2007). Scientific discourse demands skill and persistence that help students grasp the difference between scientific arguments and everyday arguments; the former emphasizes on using models and evidence with a goal of shared understanding while the latter relies on power of persuasiveness with a goal of winning (Duschl, 2008; Duschl et al., 2007; NRC, 2004, 2007). In addition, other studies showed that teachers do not have sufficient understanding of both the content to be taught and the PCK to perceive what is scientifically fruitful in students’ talk to foster productive scientific discourse (Duschl et al., 2007; NRC, 2004, 2007).

However, teacher-dominated discourse has been taken for granted in science classrooms traditionally (Webb et al., 2006). In many studies, classroom discourse with assessments and feedback is often described as recitation, Initiation-Response-Evaluation (IRE), or Initiation-Response-Follow-up (IRF) in which teachers ask students questions and evaluate their responses in a rapid sequence of questions and answers with little or no wait time (Black & Wiliam, 1998; Gee, 2010; Lemke, 1998; Webb et al., 2006). Discourse in the science classrooms must consider how to enhance students’ scientific
reasoning skills with students’ high-level cognitive thinking by providing repeated opportunities to visualize students’ idea as a process of internalization (Hicks, 1996; Vygotsky, 1979).

Any type of conversation between a teacher and students or among peers could be a productive scientific discourse that shares scientific understanding, scientific information, and values by intended use of scientific terms, concepts, or reasoning components as an instructional practice (Duschl & Gitomer, 1997). Explanation or argumentation could also be forms of productive discourse by the use of evidence and theories for explanation or claims (Kuhn, 1992; Osborne & Patterson, 2011). However, classroom discourse between a teacher and students is fundamentally not a type of argumentation or explanation in a classroom. Since teachers need to scaffold students’ participation in and to assess the students’ argumentation to guide its development (Sampson & Clark, 2006), a teacher’s role in the discourse should be supporting and guiding not persuading scientific ideas.

If supported by teachers’ feedback with awareness of students’ ways of speaking and reasoning, any types of discourse could be used to enhance students’ scientific understanding and reasoning skills through the discourse. However, with the role of support and guidance, in providing appropriate feedback, teachers should have abilities to model prototypical cases of scientific discourse to pose observations, data, patterns, and model/theories (Windschitl et al., 2008) that includes not only content knowledge but also pedagogical content knowledge (PCK) and knowledge about students’ understanding.
Engagement in discourse or activities in science classrooms usually begins with students’ interest and willingness to learn science. However, it should go beyond just participating for better grades, teachers’ evaluation, or praise but for the pleasure of learning regarded as a deep approach to learning or learning oriented engagement (Biggs, 1993; Black & Wiliam, 1998; Nystrand & Gamoran, 1991). This approach provides a useful frame of productive engagement that refers to an activated discourse with students’ ideas and opportunities to talk supported by teachers through addressing and sharing scientific problems, understanding, and scientific inquiry. When teachers foster the environment for students to be active in speaking, listening, responding with repeated opportunities to talk through discourse, students’ engagement could go beyond simply passive participation in the classroom (Hicks, 1996; Nystrand & Gamoran, 1991; Webb et al., 2006).

What instructional strategy helps teachers to enhance this type of classroom environment? Nystrand et al. (1991) maintained that students’ engagement is strongly associated with the types of instructional discourse. They identified two kinds of student engagement, *procedural* that concerns classroom rules and regulations and *substantive* that involves sustained commitment for their learning. The study showed that procedural engagement has a negative effect on students’ achievement while substantive engagement has a significant positive effect on students’ achievement (Nystrand & Gamoran, 1991; Webb et al., 2006). They gauged and showed that substantive engagement increases when teachers’ instructional discourse includes authentic questions, uptake, high-level
evaluation with incorporation of previous answers into subsequent questions (Nystrand & Gamoran, 1991).

**Teachers’ Knowledge of Scientific Discourse**

Research studies have reported that teachers’ instructional practice shapes the forms of classroom discourse, which is an integral component of science learning environments, and is sensitive to teachers’ knowledge of science (NRC, 2007; Sanders, Borko, & Lockard, 1993; Windschitl et al., 2008). Sanders et al. (1993) showed that when teachers had limited knowledge of the content, they often struggled to sustain classroom discourse with their students and found themselves trying to field student questions that they could not address. Not surprisingly, the qualities of teachers’ understanding of science are also critical to help students achieve science proficiency and positive views of science (NRC, 2004, 2007).

**Analyzing Science Classroom Discourse**

Two types of analyses have been conducted related to science classroom discourse: one is the discourse analyses and the other is a classroom observation protocol. The first one is mainly focusing on discourse that happens in science classrooms like the Critical Discourse Analysis (CDA) by Gee et al. and Semantic and Thematic discourse analysis by Lemke (Gee, 2010; Hackling et al., 2010; Hicks, 1996; Lemke, 1998). The other one analyzes or evaluates all the activities including discourse in a science classroom like Reformed Teaching Observation Protocol (RTOP), Looking inside Classrooms, and Inquiry Science Observation Coding Sheet (ISOCS), which use Likert-type evaluative or summative questionnaires (Brandon, Taum, Young, & Pottenger, 2008;
Piburn et al., 2000; Weiss, Pasley, Smith, Banilower, & Heck, 2003). All the discourse analytical tools use a dialogic episode as the unit of episode and students’ and teachers’ utterances as the unit of coding (Gee, 2010; Hackling et al., 2010; Lemke, 1998) while all the science classroom observation protocols use various evaluation criteria to judge the classroom discourse and activities that includes teacher interview and questions for detailed descriptions of the classroom characteristics (Brandon et al., 2008; Piburn et al., 2000; Weiss et al., 2003).

In science education, a few studies have examined students’ conceptual change through classroom discourse because of the practical challenges of measuring the level of reasoning and understanding separately (Hardy et al., 2010). Hardy et al. (2010) argued that conceptual understanding and level of reasoning are intertwined in classroom discourse, but they effectively analyzed these two dimensions separately with four reasoning levels of claim justification and three levels of conceptual understanding. Another study by Nystrand and Garmoran (1991) analyzed the classroom discourse by coding authenticity, uptake, level of evaluation of the teachers’ questions and responses (Nystrand & Gamoran, 1991). The study of Duschl and Gitomer (1997) identified three levels of assessment conversation in science classrooms: 1) the first stage is to receive student ideas, 2) the second stage is to recognize information from the students, and 3) the third stage is to use the information (Duschl & Gitomer, 1997).

According to Nystrand and Gamoran (1991), whole-class discourse in secondary school could be dominated by claims that are unsupported by empirical evidence (Nystrand & Gamoran, 1991). In the secondary science classrooms, Hardy et al. (2010)
also showed that the majority of the reasoning units scored on the lowest level for the claim, that is, no evidence was produced to support or refute a claim (Hardy et al., 2010). According to Nystrand (1991), significant academic achievement is not possible without sustained and substantive engagement guided by teachers in classroom discourse (Nystrand & Gamoran, 1991).

These results showed that classroom discourse with teachers’ assessment and feedback holding students’ substantive engagement could be a way of improving students’ scientific reasoning skills and conceptual understanding (Duschl et al., 2007; Hardy et al., 2010; Nystrand & Gamoran, 1991). Although teachers’ questions, prompts, and feedback have significant effects on students conceptual understanding and reasoning skills (Duschl et al., 2007; Hardy et al., 2010; Nystrand & Gamoran, 1991), characteristics of teachers’ discourse and how they affect classroom discourse to be scientific need to be studied more.

**Part II. How Teachers’ Feedback Enhances Students’ Learning**

**What is Feedback?**

Shute (2008) defined feedback as “information communicated to the learner to modify his or her thinking or behavior to improve learning.” Kluger (1998) also identified feedback as verbal or written actions by an external agent to provide an informational aspect of the learners’ task performance. Since feedback can be accepted, modified, or rejected by the recipient, Kulhavy (1985) argued that feedback is not necessarily either a reinforcement or a punishment (Kulhavy et al., 1985). Hattie (2007)
also argued that since intended praise, punishment, and extrinsic rewards were the least effective for students’ performance, they are not eligible as feedback at all. Kulhay (1985), Kluger (1998), and Shute (2008) provided an excellent claim in their reviews that feedback has a variety of effects on students’ learning due to the forms, ways, and purposes of feedback. However, they point out that the feedback effects could be either positive or negative. The fact that teachers’ feedback can have negative effects suggests that feedback methods should be considered as important knowledge for teachers.

**Formative Assessment and Feedback**

Through the book *How People Learn* (2004), the authors strongly emphasize that teachers’ feedback is extremely important in almost all science education field such as adaptive expertise, learning, transfer, and early development (NRC, 2004, Chapters 2, 3, and 4). Since teachers’ assessment and feedback can facilitate students’ thinking to be visible through various ways of discourse in writing and speaking, it is one of the best ways to accomplish goals of science education such as students’ science proficiency and habits of inquiry (Duschl et al., 2007; NRC, 1996, 2004, 2007).

As a part of classroom discourse, teachers may continually assess students’ thinking and understanding, and teachers’ feedback should be followed to scaffold students’ conceptual understanding. However, in many classrooms, opportunities for feedback rarely happen compared with assessments, but teachers often provide feedback with grades on tests, papers, worksheets, or homework to measure the results of learning (NRC, 2004, 2007). The grade is usually a flag that informs the end of the lesson and then teachers and students typically move on to a new topic and work for another set of
grades. After grading, there might be not enough time for revising students’ thinking, improving understanding, or modifying teachers’ instruction as a role of formative feedback and assessment. Formative assessment can be most valuable when students have the opportunity to receive teachers’ feedback to revise their thinking as they are learning and practicing (Black & Wiliam, 1998; NRC, 2004) and students learn how the opportunities to revise are valuable for their learning as well.

Formative assessment has been regarded as a critical tool for teachers to gain information about the progress of students’ learning, their strategies, and current levels of understanding (NRC, 2004). However, without teachers’ feedback following the assessment, the key roles of formative assessment cannot be accomplished. That is, formative assessment should be used to provide opportunities for feedback and revision to improve teaching and learning.

What is Formative Feedback?

The main function of formative feedback is to make students aware of the discrepancy between a student’s perceived status and her/his actual current learning status (Kluger & DeNisi, 1998). After acknowledging the discrepancy, teachers’ feedback can lead the students to close the gap between the goal and their current status, which means increasing students’ knowledge, reasoning skills, and conceptual understanding (Shute, 2008). Therefore, formative feedback must have three main functions: (a) reducing uncertainty about a gap between current students’ level and a desired level of learning, (b) reducing the cognitive load of the learner, and (c) providing
specific corrective information about students’ inappropriate strategies, errors, or misconceptions (Shute, 2008).

**Basic Principles of Formative Feedback**

Through the overall comparison of types, ways, purposes, circumstances of feedback, some basic principles of formative feedback could be suggested. First, formative feedback should be able to answer learners’ three main questions: “Where am I going?” “How am I doing?” and “Where to next?” (Hattie & Timperley, 2007). The first question is about what level of performance or learning is to be attained so that the students direct and evaluate their current learning status. The purpose of the feedback for the first question is to have the students set reasonable/challenging goals and track their performance (Hattie & Timperley, 2007). The feedback for the second question is to provide students specific information about their progress and about how to proceed and to lead the students to the answer to “where to next?” (Hattie & Timperley, 2007).

Kulhay et al. (1985), Kluger and DeNisi (1998), Shute (2008), and Hattie & Timperley (2004) suggest several principles or guidelines for formative feedback. Teachers’ feedback should consider various factors such as the learners’ level, task level, timing, complexity of feedback, and students’ prior knowledge. However, they have some consensus about ways for providing formative feedback:

1. Focusing on task-level not self-level. Thus, do not evaluate students’ ability compared with others.

2. Praising usually does not have any effect. Therefore, do not praise without a specific reason.
3. Informing clearly with specific message. Thus, do not say just general statements.

4. Reducing uncertainty and cognitive load to set goals. So, set up sub-goals appropriate for the students’ level.

5. Hints or correct answer could be better than no feedback but could eliminate the opportunity to think. So, use prompts and cues to guide them in the right direction.

6. Immediate feedback could be effective for some students but others may need to try by themselves. So, provide students enough time.

Besides the principles, Hattie (2007) emphasizes students’ metacognitive awareness for self-monitoring, directing and regulating their behaviors which can be triggered by teachers’ feedback. So, if teachers’ feedback provides opportunities to share students’ commitment with peers, they can see more clearly their current status and the learning goals, which can motivate them to commit to the goals. From their meta-analysis, Kluger and DeNisi (1998) also concluded that feedback is more effective when it prompts to enhance metacognition and self-regulation, such that attention is directed back to the task and causes students to invest more effort or commitment to the task (Kluger & DeNisi, 1998). For example, if praise is directed to students’ commitment for the task with specific information about how the students worked or what is done, it can enhance students’ motivation and thus can be directed back to have impact on the task (Hattie & Timperley, 2007; Kluger & DeNisi, 1998; Shute, 2008).

**Levels of Feedback**

All the researchers on formative feedback suggest the types of productive feedback, less productive feedback, and nonproductive feedback (Black & Wiliam, 1998;
Goodman, Wood, & Hendrickx, 2004; Hattie & Timperley, 2007; Kluger & DeNisi, 1996; Kulhavy et al., 1985; Mory, 2004; Shute, 2008). Through the review of research studies and papers, teacher feedback can be classified into three levels as shown in Table 2.1.

### Table 2.1 Feature of Feedback Levels by Reviewed Studies

<table>
<thead>
<tr>
<th>Level</th>
<th>Main Aspects</th>
<th>Focus</th>
<th>Feedback Content type</th>
<th>Ways of Delivering</th>
<th>Effects on Ss’ Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Evaluative, Normative</td>
<td>Self</td>
<td>Grade, Praise, Evaluation, Comparison with others</td>
<td>General comments, No reason, attention to “self”, too long, vague, difficult, or interruptive students’ prompts</td>
<td>No effects</td>
</tr>
<tr>
<td>2</td>
<td>Corrective, Verification</td>
<td>Task</td>
<td>Correction, Right answer, Direct hint, Try again,</td>
<td>Short, clear, fast in written and spoken</td>
<td>Sometimes effective</td>
</tr>
<tr>
<td>3</td>
<td>Elaborative, Facilitative</td>
<td>Task</td>
<td>Location of mistakes, Addressing information, Hint/Cue for the direction, Specific error or misconceptions (what and why)</td>
<td>No correct answers, manageable units for students, considering students’ level, specific and clear, goal orientation, flexible time management</td>
<td>Effective almost always</td>
</tr>
</tbody>
</table>

* Synthesized from the studies of Hattie & Timperley, 2007; Kluger & DeNisi, 1998; Shute, 2008

Through their reviews of teacher feedback research studies, Shute (2008), Kluger & DeNesi (1998), and Hattie (2007), strongly do not recommend the feedback that provides *too general* or *vague* information including praise or evaluation that could be ranked level 1, which has no effect or negative effects on students’ learning and performance. Level 1 feedback can includes a variety of nonproductive feedback such as wrong information, confusing information, tangential mentions distracting students’ attention, or no responses (Hattie & Timperley, 2007; Kluger & DeNisi, 1996; Shute, 2008). Without any consideration about students’ level or tasks level, teachers’ feedback is likely to be nonproductive or negative for students’ learning and motivation (Kulhavy
et al., 1985; Shute, 2008). The overall characteristics of those feedback are evaluative and normative without any specific information and reason that relates to the content they have learned.

Shute (2008) classified formative feedback into two categories: *verification* and *elaboration*. Verification is the simple information of whether an answer is correct, the most common way involves simply stating “correct” or “incorrect,” with often correct answers. On the other hand, elaboration is the information providing relevant cues to guide the learner toward a correct answer to address the topic, response, particular error, provide worked examples, or guidance. With similar ways of classification, Black and William (1998) classified feedback into two categories: *directive* and *facilitative* feedback: Providing corrective information and providing guidance and cues (Black & Wiliam, 1998). The researchers all maintained that elaboration/facilitative feedback has more positive effects on students’ performance or learning than verification/directive one (Black & Wiliam, 1998; Hattie & Timperley, 2007; Kluger & DeNisi, 1996; Shute, 2008). The verification and some part of directive feedback could be ranked level 2 while elaboration and facilitative feedback could be level 3 since the researchers recommend it more.

Level 3 feedback is teachers’ elaborative response to students’ answers and questions that could be providing relevant cues to guide the learner toward a correct answer to address the topic, response, particular error, provide worked examples, or guidance (Black & Wiliam, 1998; Hattie & Timperley, 2007; Kluger & DeNisi, 1998; Kulhavy et al., 1985; Shute, 2008). Almost all research studies on teacher feedback
maintain that this level of feedback has a strong positive effect on students’ performance or learning (Black & Wiliam, 1998; Hattie & Timperley, 2007; Kluger & DeNisi, 1996; Shute, 2008).

**Formative Feedback and Scientific Discourse**

Few studies focused on feedback’s role to enhance students’ scientific reasoning skills in science classrooms. The features of formative feedback could be applied to any subject in science classrooms and should be characterized for learning science by fostering scientific discourse. How could teachers’ feedback lead the classroom discourse to be scientific? According to Hardy’s (2010) study, teacher prompts have clear effects on students’ reasoning levels in evidence-based justifications of claims in whole-class discussions. The study shows that teacher prompts for claim of justifications significantly raised the level of students’ reasoning in associated units as students provided the requested backing such as data, evidence, or rules (Hardy et al., 2010).

A teacher’s prompt for backing of a student’s claim is one type of feedback as a response to the students’ performance. Regardless of the types of science lessons, teachers’ feedback/prompts have critical effects on students’ reasoning skills if they foster the classroom discourse to be scientific (Duschl, 2008; Gee, 2004). Scientific discourse can be framed by the process of scientific inquiry that consists of data, patterns, models or theories to explain or predict the natural world. Duschl (2008) suggested that science teachers should mediate the transition from evidence to explanation and vice versa called the evidence-explanation (E-E) continuum in students’ talk (Duschl, 2008). With teachers’ formative feedback, students would be able to engage in scientific
discourse by teacher directing or redirecting them to observations, data, patterns, and model or theories inductively or deductively. Furthermore, teachers’ feedback can provide opportunities to encourage students to produce scientific thinking which leads the discourse to sharing scientific understanding, others’ perspectives, and coordination of theories and evidence (Duschl et al., 2007; NRC, 2007).

Part III. Scientific Reasoning

What is Scientific Reasoning?

Scientific reasoning (SR) involves both conceptual understanding and inquiry skills in diverse activities such as hypothesis generation, experimental design, evidence evaluation and drawing inferences (Zimmerman, 2007). Therefore, scientific reasoning skills include the abilities: (a) to apply appropriate research methods to test hypothesis, (b) to evaluate data patterns and to use representations and models; as well as (c) to differentiate between theoretical claims, hypotheses, and evidence to support claims and hypotheses (Hardy et al., 2010). The basic principles of scientific reasoning have two facets of induction and deduction used in scientific inquiry processes. SR is also distinguished from everyday reasoning by putting very careful attention to particular kinds of evidence such as observations, data, patterns, theory or model, which combine together to form a cycle of scientific inquiry (Anderson, 2007; Bilica & Flores, 2009).

Scientific inquiry typically indicates two aspects: one is the set of scientific behaviors cognitively and physically that includes observing, collecting, comparing, contrasting, analyzing, hypothesizing, theorizing, predicting, and etc. called phases of
inquiry, the other is the set of components of inquiry that consists of observations/data (OD), patterns (PD), and theories/models (TD) (Anderson, 2007; Duschl et al., 2007; Lemke, 1998). Both are also used for scientific reasoning by connecting two aspects with ways of scientific thinking, induction, deduction, and inference. Therefore, scientific reasoning also consists of phases of inquiry, components of inquiry, and ways of thinking.

Scientific reasoning could also be regarded as an extended version of everyday reasoning, and scientific knowledge could be considered as an extension of the everyday knowledge of the natural world (Anderson, 2007; Duschl et al., 2007; Lemke, 1998). Therefore, students are likely to employ a type of scientific reasoning for their everyday experience. For example, students can make inferences by detecting patterns like the heavier object falls faster than the lighter one and they may infer that more force is exerted on the heavier one. However, this inference does not necessarily mean that students are able to choose scientific data from their experience or that they are aware of their naïve beliefs (Anderson, 2007; Duschl et al., 2007; Lemke, 1998; NRC, 2007; Zimmerman, 2007).

**Scientific Reasoning (SR) and Everyday Reasoning (EDR)**

Scientists make sense of the world by finding connections among observations, patterns, and theoretical models represented as model-based reasoning in Figure 2.1 (Revised from Anderson, 2007). Observations or data used by scientists are from experiences that can be verified, reproduced, described or measured precisely. Patterns in data such as laws, generalizations, graphs, and tables are ways of representing relationships that scientists see in the data. Scientific models and theories are designed to
explain patterns in data (Anderson, 2007; Duschl et al., 2007; Zimmerman, 2000). Two directions of reasoning includes: first, from observations to models/theories to generate new scientific knowledge as a way of scientific inquiry; second, from models to observations to describe, explain, or predict the natural world (Anderson, 2007; Duschl et al., 2007; Zimmerman, 2000). Anderson (2007) called these two inductive and deductive practices as type of scientific storytelling based on evidence and models (see Figure 2.1). As shown Figure 2.1, in addition to these reasoning processes, core knowledge of basic scientific concepts is always associated with how to select data, how to identify patterns from the data and how to infer a model as well as how to explain or predict a natural phenomenon with models (Duschl, 2008; Windschitl et al., 2008).

![Figure 2.1 Knowledge and Practices of Model-Based Reasoning Revised from Anderson, 2007, p. 12 and 18.](image)

On the other hand, students’ explanations for natural phenomena are usually based on everyday experiences that are usually not compatible with scientific models and
need to be revised to align with scientifically valid ideas (Duschl, 2008). Anderson (2007) called everyday pattern finding practical reasoning that children utilize to make sense of the world from their experiences and current knowledge. Everyday reasoning often tends to include informal metaphors or analogies that relate new experiences to familiar knowledge from previous experiences (Anderson, 2007). This aspect is not associated with a specific age but with the process of forming knowledge even in early childhood (Duncan & Hmelo Silver, 2009; Kuhn, 1989; Schwarz et al., 2009; Zimmerman, 2007). While Piagetian researchers have maintained that children do not have certain reasoning abilities until they reach an appropriate cognitive level as development of mental structures occurs, recent research studies show that even young children are capable of complex reasoning (Duschl & Gitomer, 1997; Windschitl et al., 2008; Zimmerman, 2000). Forms of scientific reasoning emerge when children are provided with multiple opportunities that sustain their engagement in scientific discourse practices with predicting, observing, explaining, and communicating (Duschl, 2008).

Both everyday and scientific knowledge have critical roles through the processes of application and inquiry, which connect experiences/observations, patterns, and models/metaphors (Anderson, 2007). Everyday knowledge includes previous experiences, practical knowledge attained with trials, or vicarious experiences that provide criteria or standards to call upon when students do everyday reasoning. Scientific knowledge also includes basic principles or concepts providing scientific standards when scientists do science reasoning connecting data, patterns, and models. Scientific and everyday reasoning have both inductive and deductive directions from experiences/data to patterns and patterns to explanations/theories and vice versa. Although scientific and everyday
reasoning have common processes in part, the nature of them does not overlap perfectly due to the conditional or hypothetical context in scientific data. Therefore, since confusing and unclear borders exist between scientific and everyday reasoning, a large challenge for students is to shift their everyday reasoning to scientific reasoning as well as for teachers to help students in changing students’ habits of everyday reasoning in science classrooms.

*Bridging Everyday Storytelling to Scientific Storytelling*

With scientific knowledge and reasoning, scientific narratives typically explain phenomena as repeating processes in systems, in contrast with everyday narrative in understanding phenomena as one-time happening events caused by actors in settings (Anderson, 2007). Everyday narratives are usually telling about the natural world relying on analogies, metaphors or other’s authorities to make stories connecting patterns in sequences of experiences (Anderson, 2007; Hardy et al., 2010; Windschitl et al., 2008).

Analogy and metaphor help us to organize our knowledge and make sense of the world, and they are used by many science teachers to explain scientific concepts without any awareness of their limitation. Such everyday knowledge learned by trial and error is often very concrete and sometimes useful until there is a conflict in accomplishing scientific understanding (Anderson, 2007). With a limited general understanding of the theory-evidence relationship, students use analogy and metaphor to manage complex science concepts (Hardy et al., 2010).

How can science teachers help students understand scientific narratives when students have habits of everyday ones? The first step could be informing how scientific
reasoning is distinguished from everyday reasoning with the concepts of scientific data, patterns, and theories and models. And then teachers’ attempts to observe and explain natural phenomena may promote scientific reasoning, especially if intended scaffolding is provided by teachers (Hardy et al., 2010; NRC, 2007; Windschitl et al., 2008).

Why are scientific narratives with scientific reasoning so important for students? They are more difficult to understand than everyday narratives, and often less interesting (Anderson, 2007). The same question might be asked regarding why scientific understanding is critical for students in a community. Most believe learning science is critical not just for the students who want to be scientists but for the students in any discipline areas, because they may face many situations that require them to select with rational reasons, that is, scientifically. Scientists suggest that the scientific narratives are special because they are well connected stories with data, patterns and models and also connected to fundamental principles such as conservation laws (Anderson, 2007).

Therefore, the natural phenomena, scientific concepts, and methods of reasoning in the scientific narratives can be more comprehensibly connected to models and evidence (Anderson, 2007; Duschl, 2007; NRC, 2004). If all of these components of science are combined and practiced through classroom discourse, scientific narratives are worthwhile for students to learn to enhance scientific understanding and reasoning skills.

*Learning Science through Scientific Reasoning*

Just as everyday reasoning involves finding and explaining patterns in experience, scientific reasoning involves finding patterns in data and developing theoretical models that explain those patterns (Anderson, 2007). From the view of constructivists, learning
must be based on individual experience as a process of constructing knowledge and understanding. Scientific reasoning is not only a goal of science education to attain scientific knowledge and ways of knowing science, but also is a way of teaching and learning for the goal. Scientific reasoning can be practiced by distinguishing data from experience, finding patterns from data, and building models to explain the patterns during classroom discourse scaffolded by teachers’ prompts and feedback.

Scientific observations/data should be precise and could be reproduced by measuring and describing the objects and events. Patterns need to clearly and explicitly represent an aspect from the data/observations as forms of laws, tables, or graphs with each unique limits of applicability and accuracy (Anderson, 2007; Duschl et al., 2007; NRC, 2004). Theoretical models need to be explicitly narrative with clear understandings of how they link to patterns and observations. A model could be taken as a metaphor but a metaphor cannot be a model. When we use a model, the model represents characteristics or patterns of the observations. For example, in the model of gas laws, molecules of gases behave like little round hard balls but it does not say it is a ball since scientists do not think of molecules as either round or hard. A model works much better scientifically than a metaphor by making accurate predictions about the phenomena based on the assumptions of the same essential characteristics of the model within specific conditions (Anderson, 2007; NRC, 2004; Windschitl et al., 2008). If patterns or models are not testable, they do not generate predictions to be checked against actual observations and cannot qualify as scientific patterns or models (Anderson, 2007; Zimmerman, 2007).
Without practicing and understanding scientific reasoning, scientific knowledge and understanding cannot be attained effectively; hence, learning science might be useless if there is no practice of reasoning and explaining a phenomenon. Learning science as a process of building knowledge should be accomplished by understanding scientific reasoning framed by scientific inquiry. Understanding what data, a pattern, and a model are could be accomplished through classroom discourse by sharing students’ idea, giving explanation, or defending claims by teachers’ well planned interactions with students. With a big picture of a lesson including how scientific understanding is connected to scientific reasoning, teachers can help students build scientific knowledge and foster scientific reasoning skills (NRC, 2007; Windschitl et al., 2008).

**Classroom Discourse to Foster Scientific Reasoning Skills**

To lead classroom discourse to be scientific, science teachers are required to have an integrated understanding of how theory, evidence, and explanation are used in inquiry and an understanding of the role of models in representing and evaluating ideas in inquiry contexts (Duschl et al., 2007; NRC, 2004; Windschitl et al., 2008). Scientific understanding includes not only scientific knowledge and the processes and elements of scientific reasoning but also the features of “what scientific is”: (1) every process described in a model is grounded in scientific observations, patterns, models and their connections as in a system, (2) scientific patterns or models should be testable in generating predictions of actual observations, (3) and there is no single scientific method in investigations, observations, and building models (Anderson, 2007; Duschl et al., 2007; NRC, 2004; Windschitl et al., 2008). In addition to these features, teachers should
understand the limits and assumptions used to build a model when applying it to the real-world by predicting and explaining events (Windschitl et al., 2008; Zimmerman, 2000).

Although students often practice scientific methods as activities, they are not asked to make claims about the implications of the components in the processes (Windschitl et al., 2008; Zimmerman, 2000). These omissions lead to a lack of understanding about the nature of scientific models. For students’ learning science through classroom discourse, sharing understanding and values can be practiced through discussion or argumentation to persuade other students using data, patterns, and models that have been checked and redirected to meet scientific standards by teachers.

As a process of building collective validation, claiming and defending in scientific discourse are essential to maintaining the quality of scientific knowledge and practice. With teachers’ formative supports, students could learn scientific authority ultimately rests in evidence-based arguments that link observations, patterns, and explanations (Anderson, 2007; Duschl et al., 2007; NRC, 2004; Zimmerman, 2000). Learning the process of scientific validation also provides the opportunity to learn that the authority is always conditional, which can be modified or replaced by new data or better evidence-based or model-based arguments (Akerson & Hanuscin, 2007; Anderson, 2007; McComas, Clough, & Almazroa, 1998).

How do science teachers utilize classroom discourse for students’ learning science? Students come to school with ways of understanding based on their experience, everyday reasoning, and simple narratives about the world limited in their precision and its power to predict and explain. On the other hand, scientists have developed ways of
understanding the natural world, based on reproducible observations, testable patterns and models, scientific inquiry and application, and peer review, which are more powerful and precise than the students’ understanding (Anderson, 2007; Windschitl et al., 2008; Zimmerman, 2000).

Learning science is more than just “learning the facts,” rather it is engaging in basic practices, pattern finding and storytelling, and pursuing knowledge with basic qualities, usefulness and connectedness (Anderson, 2007; Zimmerman, 2000, 2007). Therefore, in a classroom, students’ pattern finding and storytelling should be guided with the criteria that make scientific observations, patterns, and models especially useful for predicting and explaining the natural world.

Part IV. How CCT facilitates formative feedback in science classrooms

All technologies such as computers, software, probes, handhelds, digital cameras, and the Internet have the potential to assist teachers’ instruction and students’ integrated understanding. Since teachers have limited time to assess students’ learning and provide feedback, new advances in technology can help teachers solve this problem (NRC, 2004).

In the book The National Science Education Standards (1996), the authors state that:

A variety of technologies, such as hand tools, measuring instruments, and calculators, should be an integral component of scientific investigations. The use of computers for collection, analysis, and display of data is also part of this standard (p.175).
One major teachers’ difficulty that teachers might encounter in implementing effective instructional technology integration in their classroom is interacting with the number of students in a limited time. New advanced technologies can assist teachers to provide formative feedback, accommodate different learning styles, make students’ thinking visible, and provide scaffolding and tailored instruction to meet specific student needs (NRC, 2004; Owens et al., 2007; Pape et al., 2008; Roschelle et al., 2004; Zimmerman, 2000). Technologies such as computers, digital cameras, and the Internet have the potential to assist teachers’ instruction and students’ integrated understanding. For example, some technology can make it possible to actively engage all students in the learning process and provide immediate feedback to students about their learning.

**Connected Classroom Technology (CCT)**

One such technology used in numerous universities and colleges is the Audience Response System (ARS) or Student Response System (SRS). This technology is generally regarded as a tool to improve students’ achievement and engagement by gathering and summarizing the students’ answers (Abrahamson, 2006). CCT is an advanced ARS educational technology that has benefited from exploration efforts with many failures and reinventions (Abrahamson, 2006). Various innovations have been added to ARS such as response analysis software and networking systems (Roschelle et al., 2004).

CCT consists of both hardware and software including students’ handheld devices like a graphing calculator to “log on” to a classroom communication network that permits the instructor to send questions for students to work on and permits students to enter...
answers through their input device (Owens et al., 2007; Roschelle et al., 2004). Students’ answers can be displayed to the class anonymously either with a form of histogram or by displaying students’ individual answers. Various data for each student’s response are stored and could be analyzed to help evaluate students’ progress and revise the teachers’ instruction. This intended instructional mechanism may support formative assessment during instruction and provides both the teacher and students with feedback on how well the class is grasping the concepts under study (NRC, 2004; Roschelle et al., 2004; Shirley, 2009).

Recent research on CCT has widened to investigate effective pedagogical practices, which reveal increases in students’ positive attitude for the class with the technology (Stowell & Nelson, 2007) and shows that student engagement and conceptual learning are significantly increased when ARS is applied to the instruction (Dangel & Wang, 2008). While hundreds of research studies have been conducted on the topic of CCT and its implementation for students’ learning at the college level, limited work has been reported on the use of CCT in secondary education (Abrahamson, 2006; Pape et al., 2008; Roschelle et al., 2004). However, a few research studies have examined how CCT can be integrated for the secondary education (Abrahamson, 2006; Owens et al., 2007; Pape et al., 2008; Roschelle et al., 2004). These studies show that the technology supports formative assessment by facilitating the task of gathering information about individual students and rapid data aggregation in mathematics and science classrooms in secondary education (Irving et al., 2009; Owens et al., 2007; Pape et al., 2008; Roschelle et al., 2004). However, how CCT is implemented depends on teachers and may vary from a
marginal to a more dominant role in different classrooms (Caldwell, 2007; Dangel & Wang, 2008; Roschelle et al., 2004; Stowell & Nelson, 2007).

Features of CCT

Although specific methods to facilitate teachers’ instruction for students’ learning varies (Abrahamson, 2006; Irving et al., 2009; Pape et al., 2008; Stowell & Nelson, 2007), CCT seems to have direct effects on: (a) increased students’ engagement, (b) increased opportunities for feedback with formative assessments, and (c) increased teachers’ awareness about students’ understanding (Abrahamson, 2006; Caldwell, 2007; Irving et al., 2009; Pape et al., 2008; Reay et al., 2008; Shirley, Irving, Sanalan, Pape, & Owens, 2009). Because the most critical feature of this technology is to provide information about students’ understanding with statistical data and individual data, questions posed using CCT have the aspects of formative assessment which should be followed by formative feedback.

Therefore, since CCT allows a teacher to project questions to the entire class and instantly collects and summarizes student responses for both teachers and the students, teachers’ feedback could be the best way to integrate the information effectively and efficiently for students’ learning (Abrahamson, 2006; Hattie & Timperley, 2007; NRC, 2004; Owens et al., 2007). Although teachers have much information about students’ learning status, if they do not use it or use it inappropriately there might be negative effects on students’ learning (Kluger & DeNisi, 1996; Shute, 2008). With or without the use of this technology, teachers’ feedback to students’ responses should provide scaffolding for students’ learning (Hattie & Timperley, 2007; Kluger & DeNisi, 1998;
Shute, 2008). With various and sufficient information about an individual’s or group’s learning status, teachers’ feedback has much more potential if teachers deliver feedback appropriately. So, when teachers use this technology, how they provide feedback is ultimately critical because it could have positive or even negative effects on students’ motivation and learning (Hattie & Timperley, 2007; Kluger & DeNisi, 1998; Shute, 2008).

**How CCT Facilitates Teachers’ Feedback**

Some of the purposes of using the educational technologies include giving students and teachers more opportunities for feedback, reflection, and revision besides bringing exciting curricula based on real-world problems into the classroom (Irving et al., 2009; NRC, 2004; Owens et al., 2007). The environment with CCT makes it easy for students to be informed specifically about their own and other’s learning status and increases the opportunities to value teachers’ timely feedback. Most classroom connectivity technologies, such as ARS, can promote more active engagement in large lecture classes (Caldwell, 2007; Reay et al., 2008) and, if used effectively, it highlights the reasoning processes that students use to solve problems (NRC, 2004).

Research studies on this technology commonly report that students appear to be more active participants in the class by asking and answering more questions and engaging in more lively discussion since it produces the sense of community and competency by seeing that they are not the only ones with difficulty or confusion (Abrahamson, 2006; Caldwell, 2007; Irving et al., 2009; National Research Council, 2004; Pape et al., 2008; Roschelle et al., 2004). When teachers engage all students in
formative assessments and then give them formative feedback on their learning, students can appreciate the opportunities to revise and rethink their ideas for better learning, which affects the students’ approaches to learning not just for performance represented by grades but also for actual learning with cognitive activities (Biggs, 1993; Caldwell, 2007; NRC, 2004; Owens et al., 2007; Roschelle et al., 2004).

A teacher with this technology can prepare, display, and send questions to the class individually or as a group working collaboratively. Students can send their responses via handheld devices, and the teacher collects, stores, and displays histograms that show how many students have right answers in the class. This could be a form of classroom discourse providing useful potential feedback to students and the teacher on how well the students understand the content. Teachers may use this information to guide their instruction.

However, CCT does not guarantee effective learning by itself. The display of students’ responses should be used for leading the classroom discourse to be scientific by sharing students’ thinking about the procedures of reasoning for their answers, listening critically to others’, and refuting or offering alternative reasoning strategies (Caldwell, 2007; Irving et al., 2009; NRC, 2004). This technology could be used for only facilitating IRE or IRF discourse patterns, that is, giving questions, receiving answers and informing about right answers or following questions which would not enhance productive discourse or make students’ reasoning more visible (NRC, 2004; Roschelle et al., 2004).
Part V. Teachers’ Feedback in Classroom Discourse for Scientific Reasoning

As discussed above, learning science should be accomplished through practicing scientific discourse and reasoning so that students appreciate the usefulness and connectedness of scientific knowledge (Duschl, 2008; Lemke, 1998). To attain the habits of scientific reasoning framed by scientific inquiry, students must have enough opportunities to engage in scientific discourse, which shares scientific language and reasoning tools with observations, patterns, and models (Duschl & Gitomer, 1997; Hackling et al., 2010). In a scientific discourse, students can use their observations as evidence to defend their claims, use scientific models to explain or predict an observation, and use them all together to engage in scientific storytelling.

How do science teachers have their students engage in classroom discourse or activities with scientific content that students may find uninteresting? They can provide rewards for the engagement, praise students, give extra grades, or prepare fun activities or films. All these things could be successful strategies for students’ motivation, self-efficacy, or engagement. Although current science teaching has a strong focus on activity with investigation and materials, learning science can be completed through talk where teachers and students are able to work on ideas and develop understandings (Hackling et al., 2010; Lemke, 1998). Many activities provide students with experiences but the purpose of the activities should be for discourse. That is, activity and discourse must work together to support the development of students’ understandings and build scientific literacy (Hackling et al., 2010; Lemke, 1998). Therefore, with any pedagogical strategy, teachers’ instructional habits to lead a class as a community of learning science are
essential requirements. At any moment, when students need support, even though they do not realize it, *teachers’ prompts or feedback* must lead them to the *scientific discourse*.

**The Role of Teachers’ Feedback for Scientific Discourse**

With formative feedback, science teachers can enhance student’s motivation and metacognition and foster conceptual understanding and scientific reasoning (Kluger & DeNisi, 1996; Shute, 2008). If science teachers know how formative feedback works and what scientific discourse is, they can apply their feedback to lead classroom discourse to be scientific (see Figure 2.2).

![Figure 2.2 Teachers’ Feedback to Foster Scientific Reasoning Skills through Scientific Discourse.](image)

As shown in Figure 2.2, some aspects of formative feedback correspond well to characteristics of scientific discourse such as informing about discrepancies, prompting...
justifications, and providing opportunities to think. This type of talk scaffolded by formative feedback is most valued in science education, which promotes reasoning, as it is required to develop scientific understanding (Hackling et al., 2010; Lemke, 1998).

Duschl (2008) suggests that important teachers’ roles include creating learning contexts in which students can use evidence in scientifically meaningful ways as well as creating opportunities for monitoring and assessing students' appropriate use of evidence. In particular, teachers’ feedback can play a critical role in the construction of scientific discourse routines, by providing opportunities for students to establish scientifically valid reasoning patterns (Hardy et al., 2010). Teachers’ feedback for students to use evidence or theories to support their claims may contribute to a classroom climate, fostering scientific reasoning, and also contribute to the development of individual students’ reasoning skills.

Figure 2.3 Learning Science through Classroom Discourse
As shown in Figure 2.3, teachers’ feedback must support transferring students’ explanations and inferences with their everyday experiences and reasoning to scientific observations, pattern finding and building models. Teachers’ feedback in a classroom discourse can encourage students to engage in sharing a diversity of ideas and scientific representations. Like teachers’ prompts, feedback can lead students to construct, coordinate, and reflect upon accompanying evidence to achieve conceptual understanding based on the coordination of theory and evidence (Hardy et al., 2010). Three steps of feedback can be suggested like the three stages of assessment conversations by Duschl and Gitomer (1997), receiving information, recognizing information, and using information. First, a teacher needs to be aware of students’ talk to receive the information about what is missing to be scientific and then consider what information is needed and how to provide it. Finally, the teacher can provide feedback for the students’ improvement in various ways. The feedback content could be focused on essential elements of scientific reasoning, such as looking at relationships, consistency, or use of examples as a means of promoting discourse concerned with reasoning processes rather than facts.

In addition to leading students to scientific discourse, effective feedback by teachers should be able to create discrepancies that provoke cognitive activity that promotes more complex, abstract, and developed cognitive representations (Duschl & Gitomer, 1997). Many researchers argued that successful science education depends on students’ involvement in forms of communication and reasoning that triggers students’ high level of thinking (Anderson, 2007; Duschl et al., 2007; Nystrand & Gamoran, 1991; Windschitl et al., 2008) that has specific ways of dealing with evidence; generating,
testing, and evaluating theories; and communicating ideas (Anderson, 2007; NRC, 2004, 2007; Zimmerman, 2007). Higher levels of scientific reasoning skills can occur only in the context of conceptually rich explorations where students engage in the forms of reasoning that are intrinsic to scientific activity and science as a way of knowing (Hardy et al., 2010; NRC, 2007).

Learning science could be designed by both epistemic and social goals of science through scientific discourse, such as explanation, argumentation, model building, debate, and decision making (Duschl, 2008). Therefore, the development of scientific discourse practices is central to learning science; if teachers’ feedback leads students to make their thinking visible, it is the most effective way in which knowledge deepens, reasoning develops and learning progresses (Anderson, 2007; Duschl et al., 2007; Windschitl et al., 2008).

Science teachers are always looking for ways to make students’ scientific understanding more useful and more connected to their real life. As discussed above, there are fundamental differences between students’ and scientists’ reasoning about the natural world but there are also prospective ways to connect with each other (Anderson, 2007; NRC, 2004; Windschitl et al., 2008) depending on the teachers’ instructions. This is a major challenge for teachers especially in classes where what students expect to memorize content. In science classes, however, students should be able to see the differences and to develop the ability to reason more like scientists in the process (Anderson, 2007; NRC, 2007; Windschitl et al., 2008).
How does Teacher Feedback Bridge the Gap between ER and SR?

Researchers suggest basic principles for science teachers to foster scientific discourse by teacher feedback to help students with bridging scientific reasoning and everyday reasoning (Duschl, 2008; Hackling et al., 2010; Hicks, 1996; Windschitl et al., 2008). The diagram Figure 2.4 can illustrate the suggested ways.

Figure 2.4 Possible Feedback Paths for Scientific Reasoning

1. Provide more opportunities to engage in the classroom discourse either written or spoken. Practicing speaking and writing with data, patterns, and models will make science knowledge meaningful and useful.

2. Support students’ ideas and help them to connect with observations, patterns, and models in various ways.
• To connect students’ everyday experiences (EX) to scientific observations/data (OD), patterns from data (PD), and models/theories (MT).

• To compare, contrast, generalize, analyze, or synthesize by using the selected and collected observations/data (Path OD to PD)

• To connect the patterns to models/theories and the models to explanations and predictions of related phenomena. (Path OD to MT)

• To explain or predict connecting different representations of observations, patterns, and models. (Path MT to PD and OD)

3. Help students learn that the values and connectedness of scientific knowledge eventually relies on observations and data from the natural world, not on authority of teachers, textbooks, or celebrities.

**Theoretical Framework**

From a social constructivist view, the cognitive values of discourse in science education involve the public implementation of reasoning to transfer into students’ own experience (Hackling et al., 2010; Hicks, 1996; Lemke, 1998; Vygotsky, 1978) (see Figure 2.5). Vygotsky (1981) said

Any function in the child’s cultural development appears twice or on two planes. First it appears on the social plane, and then on the psychological plane. First it appears between people as an interpsychological category, and then within the child as an intrapsychological category (p.163)
When students engage in classroom discourse, the interaction among a teacher and peers can promote this internalization with appropriation and the development of knowledge, beliefs, and values. In science classrooms, the phases of scientific inquiry such as understanding, analyzing, or hypothesizing can be considered as a zone of proximal development (ZPD) which refers to an expected level that can be reached by assistance of others (Vygotsky, 1978). Teachers’ timely and appropriate feedback, called formative, can inform students about the gap between students’ actual development level and potential development level (Kulhavy et al., 1985; Shute, 2008; Vygotsky, 1978). Furthermore, as scaffolding instruction, teachers provide students with supports to facilitate development to internalize new information building on prior knowledge, which is helping the learner to reach the ZPD (Lemke, 1998; National Research Council, 2004; Vygotsky, 1978).

Figure 2.5 shows how students’ science learning happens with phases of scientific reasoning by externalizing students’ ideas by teachers’ feedback and by internalizing the phases as their experiences through a classroom discourse. Students’ ideas should have the opportunities to be externalized through classroom discourse and then, they can be internalized by individuals with scaffolding assistance by teachers. Therefore, science teaching and learning must start by exploring students’ prior experiences by stimulating them to engage in discourse (Connecting Experience), and providing experiences of scientific observations so that students can have a conflict or comparison with their experiences (Providing a Situation). Before moving on to scientific explanations, students should have the opportunities to develop their own questions about the situation and to identify what data can answer their questions (Identifying Questions and Data). Using the
data obtained by measuring or describing attributes and values, students need to practice finding patterns and they should have opportunities to talk about how they identify patterns (Identifying Patterns). Before formal scientific explanations are introduced, students should be given an opportunity to develop their own scientific ideas to explain the patterns and observations (Constructing Models). After introducing formal scientific theories, comparing them with their ideas will provide opportunities to internalize building on their ideas and experiences (Comparing Explanations). Finally, predicting an event or result within a situation developed by the students will be highest level of cognitive practices with designing, evaluating, and synthesizing (Predicting Events).

Figure 2.5. Science Classroom Discourse with Phases of Scientific Reasoning and Teacher Feedback
Summary

In this chapter, I first reviewed the classroom discourse and scientific discourse, followed by second how teachers’ feedback enhances classroom discourse to be scientific for students’ learning. Since I think science classroom discourse should be scientific, I reviewed what scientific is. In science education, “scientific” can be explained by scientific inquiry as a method to discover natural phenomena. As a form of discourse, claims and argumentation can occur at any time in science classrooms. Framed by scientific inquiry, science classroom discourse could be scientific by using empirical evidence and theoretical models that enhance students’ scientific reasoning skills.

Therefore, I reviewed what scientific reasoning is and how it differs from everyday reasoning. One of the purposes of science education is to improve students’ scientific reasoning skills by transforming them from everyday reasoning. Teachers’ feedback could play a role facilitating this bridging when applied appropriately with teachers’ knowledge of students status and scientific reasoning. As a part of classroom discourse, teachers’ feedback should lead the classroom talk to be scientific by providing more opportunities to reflect on students’ thinking.

Researchers define feedback as information for the learner to modify his or her thinking or behavior to improve learning (Kluger, 1998; Shute, 2008, Hattie, 2007). Because feedback effects could be either positive or negative, the researchers point out that the feedback method should be considered as important knowledge for teachers. The main function of formative feedback is to make students aware of the discrepancy and to lead the students to close the gap between the goal and their current learning status (Shute,
Researchers suggest several ways to implement formative feedback that consider various factors such as the learners’ level, task level, timing, complexity of feedback, and students’ prior knowledge.

By prompting with teachers’ feedback in classroom discourse, an appropriate practice of students’ listening and speaking scientific talk such as clarifying evidence, defending claims, and coordinating scientific knowledge can foster students’ ability to identify data and patterns, build models, and predict and explain theories and observations (Herrenkohl & Guerra, 1998; Hicks, 1996; Van Zee & Minstrell, 1997). However, in a science classroom, teacher-dominated discourse has been taken for granted in which teachers do most of the talking and students are rarely asked to share their thinking (Webb et al., 2006).

Although scientific and everyday reasoning have common processes in part, the nature of them does not overlap perfectly due to the conditional or hypothetical context in scientific data. Therefore, informing how scientific reasoning is distinguished from everyday reasoning with the concepts of scientific data, patterns, and theories and models can be the first step toward enhancing students’ scientific reasoning skills (Hardy et al., 2010; National Research Council, 2007; Windschitl et al., 2008). With teachers’ formative feedback to foster scientific discourse, students could learn that scientific authority ultimately rests on evidence-based arguments that link observations, patterns, and explanations (Anderson, 2007; Duschl et al., 2007; NRC, 2004; Zimmerman, 2000).

Some new technologies can make it possible to actively engage all students in the learning process and provide immediate feedback to students about their learning. CCT is
an advanced ARS educational technology with various innovations that have been added to ARS such as response analysis software and networking systems (Roschelle et al., 2004). The purposes of using the educational technologies includes giving students and teachers more opportunities for feedback, reflection, and revision besides bringing exciting curricula based on real-world problems into the classroom (Irving et al., 2009; NRC, 2004; Owens et al., 2007). With the technologies, science teachers can provide formative feedback effectively to enhance student’s motivation and metacognition and foster conceptual understanding and scientific reasoning (Kluger & DeNisi, 1996; Shute, 2008).

If science teachers know how formative feedback works and what scientific discourse is, they can apply their feedback to lead classroom discourse to be scientific. Some aspects of formative feedback correspond well to characteristics of scientific discourse such as informing about discrepancies, prompting justification, and providing opportunities to think (Lemke, 1998).

In the next chapter, the development of an analytic tool and application of that tool for the analysis of science classroom discourse will be presented. How the tool and the coding scheme are synthesized in the frame of scientific reasoning and formative feedback will also be discussed.
Chapter 3 : Methodology

The purpose of this study is to develop an analytical framework and a tool for assessing science classroom discourse with CCT. The data analyzed in this study are from a larger research project, Classroom Connectivity in Promoting Mathematics and Science Achievement (CCMS). The study also demonstrates how the framework and tool can be used to characterize teacher’s questioning and feedback during classroom discourse. In this chapter, the first part will present brief description about the CCMS study’s intervention and data used in this dissertation study. In the second part, how the analytical framework and tool were developed and how it measures classroom discourse will be presented. The second part includes redefining terms, defining unit of episode and coding, classifying levels of feedback and teachers’ questioning used in this study.

Part 1. CCMS Project and Data Collection

The CCMS project is a multi-year longitudinal study of the effect of connected classroom technology (CCT) in mathematics and science classrooms. The overall CCMS project design is a randomized cross-over trial where the control group was exposed to the intervention sequentially. In the first year of the study, one cohort of teachers received the intervention and a second cohort of participants (teachers) served as a control group; in the second year, the control cohort received the intervention. In addition to
implementation of technology into their classrooms, the intervention for participants consists of four parts: 1) provision of CCT (TI NavigatorTM), 2) professional development (PD), 3) online training and discussion forum, and 4) follow-up PD at an annual technology conference (Irving et al., 2009; Owens et al., 2007). A variety of qualitative and quantitative measures were used to examine teacher implementation, student perceptions and achievement as variables of the CCMS study.

*Classroom Connectivity Technology (CCT) applied in CCMS study*

CCT is a networked system with students’ handheld devices connected to the teachers’ computers which shares a display screen to increase communication between students and teachers (Owens et al., 2007; Pape et al., 2008; Roschelle et al., 2004). Connected classrooms in this study were equipped with the TI-NavigatorTM, a system connecting each student’s handheld calculator, typically a TI-84 Plus, with the teacher’s computer (see Figure 5).

![Figure 3.1. Depiction of the TI Navigator™ within a classroom](image-url)
Components of Navigation System

The TI-Navigator™ has four components (see Table 3.1). The teacher can pose a single question using Quick Poll, and several questions can be sent to the students’ calculators with Learning Check. These questions include multiple-choice, true/false, or open-ended formats. Class Analysis summarizes students’ responses, which may be displayed as bar graphs. Using the fourth feature, Screen Capture, the teacher can take a “snapshot” of each student’s individual calculator screens for display. The fifth feature, Activity Center, allows the teacher to display a coordinate system (Owens et al., 2007; Pape et al., 2008).

Table 3.1 Components of TI-Navigator

<table>
<thead>
<tr>
<th>Component</th>
<th>Purpose</th>
<th>Process</th>
<th>What to send</th>
<th>What to display (receive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quick Poll</td>
<td>To assess the degree of students’ understanding.</td>
<td>a. To pose a question b. To collect students’ responses c. To analyze students’ responses d. Feedback and class discussion</td>
<td>a. Multiple choice b. True or false c. Likert-type d. Open-ended questions</td>
<td>a. Summary bar graph of responses b. All unique responses</td>
</tr>
<tr>
<td>Learning Check</td>
<td>To increase teachers’ knowledge of what students have learned.</td>
<td>a. To send multiple assessment questions b. To aggregate student response data c. To lead class discussion</td>
<td>a. A set of quiz b. Send documents c. Short assessment</td>
<td>a. Histogram of Aggregate results b. Students’ responses of each question</td>
</tr>
<tr>
<td>Screen Capture</td>
<td>To see what students are doing and diagnose students’ errors</td>
<td>a. To take a snapshot of each calculator screen b. To foster class discussion c. To show students’ different solution strategies</td>
<td>a. Students’ calculator snapshot to the teacher’s computer</td>
<td>a. Students’ calculator screen as they each enter the answer</td>
</tr>
<tr>
<td>Activity Center</td>
<td>To develop students’ conceptual learning by doing activities with graphs and equations</td>
<td>a. To participate an experiment with graph b. To collect and analyze data c. To diagnose incorrect responses c. To engage the class in discussion</td>
<td>(To the teacher’s computer) a. Individual colored and shaped cursors b. Table of values c. Graph on the coordinate plane d. Algebraic equation</td>
<td>a. A coordinate system b. Individually colored and shaped cursors c. Values, Graph and equations</td>
</tr>
</tbody>
</table>
Data Produced in the CCMS Study

The CCMS study produced various qualitative and quantitative data. Qualitative data included student focus group (SFG) interviews, teacher post observation interviews (POI), telephone interviews, and classroom observations. All interview and observation video had the audio recorded, transcribed, and stored in the project web server, which the researchers and participants can access in this study. Quantitative data are various surveys and students’ achievement tests conducted by students or teachers. All the quantitative data were also stored in the webserver and were accessible only by permission to research team participants. In this dissertation study, however, only classroom observation videos and transcripts have been analyzed since the purposes are to develop an analytical framework and tool to assess science classroom discourse.

Classroom Observations

Each teacher was observed teaching at least two science classes on two successive class meetings, for a total of four class periods per teacher. Each lesson was videotaped and transcribed. Original videotapes were viewed in order to capture specific details such as exact wording of Quick Poll questions and open-ended student responses. In addition to the original transcripts, essential annotation was added with information regarding nonverbal actions such as gestures, physical movements, and screen/board displays.
Data Collection

Participants

All participants where data were used in this study constituted a subset of a larger pool (Math Cohort 1 and 2, N = 127, Science Cohort 3 and 4, N = 12). From the group cohort 3, five physical science teachers who had completed their first year of the CCMS study as members of the experimental group were selected with their students (N= 242) from five schools located in four states (see Table 3.2). For this dissertation study, a convenience sampling method was used to have complete data sets of classroom observations with the same subject. All the teachers selected for this dissertation study taught physics content such as velocity, motion graph, or waves in their observed classroom instruction.

Table 3.2 Participant Information

<table>
<thead>
<tr>
<th>Teacher</th>
<th>State</th>
<th>Locale</th>
<th>Grade levels</th>
<th>Undergraduate Major</th>
<th>Years teaching</th>
<th>Participation Year</th>
<th>Teaching Subject</th>
<th>Observation videos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ann</td>
<td>TX</td>
<td>Large city</td>
<td>7</td>
<td>Animal Science</td>
<td>4</td>
<td>1</td>
<td>Physics</td>
<td>Y1(4)*</td>
</tr>
<tr>
<td>Ben</td>
<td>PA</td>
<td>Urban fringe of a large city</td>
<td>7</td>
<td>Physics</td>
<td>2</td>
<td>1,2,3</td>
<td>Physics</td>
<td>Y1(2), Y2(3)</td>
</tr>
<tr>
<td>Cory</td>
<td>OH</td>
<td>Mid-size city</td>
<td>10</td>
<td>Elementary Ed</td>
<td>16</td>
<td>1,2,3</td>
<td>Physics</td>
<td>Y1(4)</td>
</tr>
<tr>
<td>Daisy</td>
<td>OH</td>
<td>Urban fringe of a large city</td>
<td>10</td>
<td>Secondary Ed</td>
<td>3</td>
<td>1,2,3</td>
<td>Physics/Chemistry</td>
<td>Y1(1), Y2(4)</td>
</tr>
<tr>
<td>Eva</td>
<td>VA</td>
<td>Urban fringe of a large city</td>
<td>10/11</td>
<td>Geophysics</td>
<td>21</td>
<td>1,2,3</td>
<td>Physics</td>
<td>Y1(5)</td>
</tr>
</tbody>
</table>

* Y1(4) – 4 videos and transcripts analyzed in Year 1

The observed and analyzed classroom observation videos in this study are four or three consecutive classes for two or three days due to the each teacher’s schedule. What
types of data from the observations and transcripts and how they are analyzed will be presented in the next section with detailed descriptions. The participants were especially interesting because of their various ways of integrating CCT in widely divergent ways in their teaching experience and school contexts. Although, six kinds of data have been collected in CCMS study, observations, POI, telephone, SFG interviews, student survey, and student achievement data, this dissertation study only uses classroom observation data.

**Triangulation of Data**

Golafshani (2003) points out that reliability and validity in qualitative research could be replaced by the idea of trustworthiness. Triangulation is generally suggested as the way of improving trustworthiness of qualitative research including grounded theory (Glaser & Strauss, 1967; Miles & Huberman, 1994; Mills, 2003). Table 3.3 is a data triangulation matrix that will make it possible to explore how the CCT could affect students’ learning.

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Students in Science</th>
<th>Data Sources</th>
<th>Teachers</th>
<th>Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student Perception</td>
<td>SFG interviews,</td>
<td>SFG interviews,</td>
<td>POI*,</td>
<td>Observations</td>
</tr>
<tr>
<td></td>
<td>Surveys(MSLQ, SPIS)</td>
<td>Surveys(MSLQ,</td>
<td>Telephone</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SPIS,SVAS)</td>
<td>interviews</td>
<td></td>
</tr>
<tr>
<td>Teachers’ Use of CCT</td>
<td>SFG interviews</td>
<td>SFG interviews</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SPIS</td>
<td>SPIS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Students’ Achievements</td>
<td>Pre-, Posttest</td>
<td>Pre-, Posttest</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Post Observation Interview

Table 3.3 Data Triangulation Matrix
However, in this study, since the purposes are to develop an analytical framework and tool as well as how they identify the characteristics of the classroom discourse, data analyses focus only on classroom observations and discourse in them. Comparisons and contrasts with the other data analyses are all left for the future studies because of the amount of data, narrowed research questions, and need for data redisposition.

**Part 2. Data Analyses**

As discussed in Chapter 2, science classroom discourse can be an effective method for productive learning of scientific knowledge and reasoning skills. Teacher feedback in supporting scientific classroom discourse can improve students’ scientific understanding by connecting scientific inquiry components to reasoning methods. The connection among classroom discourse, scientific reasoning, and scientific inquiry can be accomplished by formative feedback practices.

Classroom talk should not be dominated by teachers but the teacher might be only the one who leads the classroom discourse. The more critical issue is how the teacher leads classroom discourse to be scientific for students’ science learning. This study clarifies the role of teacher feedback in supporting scientific discourse and how the discourse connects the phases of scientific inquiry to develop a pedagogical framework that supports a discourse of inquiry.

The use of connected classroom technology (CCT), a type of classroom communication system, may affect teachers’ implementation of formative assessment and feedback in their instructional practices. Previous studies in CCT reveal that it provides
information about students’ learning status and shows positive effects on students’ learning (Irving et al., 2009; Roschelle et al., 2004; Shirley, 2009), but how it facilitates teachers’ instruction remains to be clarified. If CCT plays a role in how teachers and students communicate, instructional changes may occur in classroom discourse.

This dissertation study has developed a conceptual framework that encompasses scientific discourse, scientific reasoning, and formative feedback (Figure 3.3). By combining the conceptual model and aspects of formative feedback, the classroom discourse analytical table (CDAT) has been developed (see Table 3.8). With CDAT, the following research questions have been explored:

1. How does the analytical tool characterize the classroom discourse with teachers’ questioning and feedback?

2. How does the analytical tool identify how teachers promote scientific classroom discourse?

3. How does the analytical tool identify the difference in discourse between the classroom with CCT and without CCT?

In this chapter, how the data has been collected, how CDAT was developed, and the outlines of data produced by CDAT will be presented first. The methodology overview includes defining some terms used in this study and descriptive statistics of five teachers’ classroom discourse components defined in this study.
Reframing Science Classroom Discourse

In this section, the definitions of several terms used in this study will be presented: classroom discourse, classroom talk, a discourse episode, a dialogue, sub-Question, feedback-Question, Length of Dialogue (LOD). Since the purpose of this study is to identify how science teachers lead and support classroom discourse focusing on teachers’ talk, questioning, and feedback, it does not examine student-student talk but only focuses on any types of communications between a teacher and students in the science classroom.

Classroom discourse refers to language-in-use that teachers and students communicate with each other in the classroom (Cazden, 2001; Gee, 2004). As a scientific community, science classrooms need to have shared scientific understandings, values and assumptions (Cazden, 2001; Gee, 2004; Lemke, 1998). Therefore science classroom discourse should be a mirror of scientists’ discourse by engaging students in observing, describing, comparing, classifying, analyzing, discussing, hypothesizing, theorizing, questioning, challenging, arguing, designing experiments, following procedures, judging, evaluating, deciding, concluding, generalizing, reporting, writing, lecturing, and teaching in and through the language of science (Lemke, 1998). However, a science classroom is not always full of science, but consists of many different kinds of talk, activities, discipline, management, and entertainment as well as some funny jokes. In this study, classroom discourse is differentiated from other types of talk as discursive dialogues between a teacher and students about scientific content in a science classroom.
Components of Classroom Discourse

In this study, scientific classroom discourse is defined as the communication about scientific content between a teacher and students and other types of talk are considered as classroom talk. From the analyses of the classroom instructions, the classroom activities mainly consist of lectures, experiments, reviews of problem solving, reviews after an experiment, and demonstrations. Besides the classroom activities, the teachers in this study spend class time disciplining and managing students’ behavior. Table 3.4 shows the percentages of classroom discourse time compared to whole class time and classroom talk time. It shows all the classes spend their time in communication between a teacher and her/his students for almost 40% of the total class time. However, only about 25% of class time about 11 minutes per class is spent for classroom discourse. The classroom discourse time shown in Table 3.4 is normalized in a class time of 50 minutes and these classroom example data do not represent all teaching done during a whole academic year.

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Total Class Time (h:m:s)</th>
<th>All Classroom Talk* (%)</th>
<th>Classroom Discourse (%)</th>
<th>Classroom Discourse (minutes/50min)</th>
<th>Science Content</th>
<th># of Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ann**</td>
<td>3:36:26</td>
<td>41.21</td>
<td>19.93</td>
<td>9.59</td>
<td>Speed, Velocity, Graph</td>
<td>4</td>
</tr>
<tr>
<td>Ben</td>
<td>7:01:37</td>
<td>32.27</td>
<td>15.02</td>
<td>6.21</td>
<td>Electronics, Energy, Motor Speed, Velocity, Graph</td>
<td>5(Block)</td>
</tr>
<tr>
<td>Cory</td>
<td>3:03:09</td>
<td>58.68</td>
<td>37.40</td>
<td>17.52</td>
<td>Speed, Velocity, Graph</td>
<td>4</td>
</tr>
<tr>
<td>Daisy</td>
<td>3:34:52</td>
<td>49.90</td>
<td>32.24</td>
<td>13.51</td>
<td>Speed, Velocity, Graph Wave Phases Frequency, Wavelength</td>
<td>5</td>
</tr>
<tr>
<td>Eva</td>
<td>4:17:56</td>
<td>35.09</td>
<td>22.25</td>
<td>11.30</td>
<td>Speed, Velocity, Graph Wave Phases Frequency, Wavelength</td>
<td>5</td>
</tr>
<tr>
<td>total</td>
<td>21:34:00</td>
<td>43.43</td>
<td>25.37</td>
<td>11.46</td>
<td>Speed, Velocity, Graph Wave Phases Frequency, Wavelength</td>
<td>23</td>
</tr>
</tbody>
</table>

*Excludes student-student talk, ** Pseudonyms
Although the class time includes inquiry activities, students’ seatwork, classroom management, various announcements, and classroom settlement, the portion of discourse time of some teachers is less than ten minutes in a class. During the discourse time, teachers also choose to spend some time on off topic talk to encourage students to participate in the discourse.

**Discourse Episodes, Dialogues, and Utterances**

In this study, class components are reframed for the analysis. A class consists of classroom activities and classroom talk, and on the other hand, classroom talk consists of classroom discourse and other talk, while classroom discourse includes several classroom episodes that consist of several dialogues and a dialogue consists of students’ and a teacher’s utterances (see Table 3.5). Table 3.5 shows what components of the classes are used for the analysis in this study. Among these components, each teacher’s or students’ utterance was analyzed as a unit of coding and a dialogue between a teacher and students was coded as unit of episode. A CDAT is for a dialogue and a few dialogues and each utterance in a dialogue was coded in an appropriate cell in the CDAT. The coding process will be presented in the later sections of this chapter.
Table 3.5 Components of a Class

<table>
<thead>
<tr>
<th>Classroom Activities</th>
<th>Whole Classroom Talk (Between a teacher and students)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Off Topic Talk</td>
</tr>
<tr>
<td></td>
<td>Managing or disciplining students’ behaviors</td>
</tr>
<tr>
<td></td>
<td>Explaining about activities, grades, test, or etc.</td>
</tr>
<tr>
<td></td>
<td>Classroom Discourse on Topic</td>
</tr>
<tr>
<td></td>
<td>Episode 1</td>
</tr>
<tr>
<td></td>
<td>Dialogue 1</td>
</tr>
<tr>
<td></td>
<td>Teacher’s Utterances and Students’ Utterances</td>
</tr>
<tr>
<td></td>
<td>Episode 2</td>
</tr>
<tr>
<td></td>
<td>Dialogue 2</td>
</tr>
<tr>
<td></td>
<td>......</td>
</tr>
</tbody>
</table>

**Coding Units: Discourse Episodes**

As shown Table 3.5 above, the components of classroom discourse are episodes, dialogues, and utterances in this study. In this study, a discourse episode is determined as a teacher-students conversation about scientific content between other classroom activities such as experiments or problem solving seatwork. Therefore, an episode can have several dialogues with various topics and a dialogue would have a few or many utterances. A CDAT is for coding one dialogue or several dialogues depending on the dialogue’s length. In the case of coding several dialogues in a CDAT, each dialogue must have different one digit number (see Dialogue and CDAT examples in the next section).

**Coding Units: Discursive Dialogues**

Gee et al. (2004) also defined a series of turns of talk that all relate to the same topic or theme as an episode unit. In this study, however, a dialogue between a teacher and students is defined as a unit of episode that consists of consecutive utterances. When a dialogue starts, the first question will be assigned a new number and in the same
dialogue, all added utterances have decimal notation such as 1.1, 1.2, 1.3, and etc. (see Dialogue and CDAT examples in the next section).

**Coding Units: Utterances**

In their book introducing Critical Discourse Analysis (CDA), Gee et al. (2004) defined “Utterance” as a unit of speech that corresponds to any uninterrupted stretch of speaking by one or more people. Gee added a description of utterances as a unit of discourse analysis:

> Within a dialogical approach to language, the utterance (rather than the phoneme, morpheme, word, phrase, or sentence) is the basic element of language in use. ... From the point of view of analyzing individual contributions to dialogue, the change of speaking subjects or turn taking is a natural unit of analysis (p.87).

Likewise, Hicks (1995-6) maintained “Whereas sentences were defined by their formal structure, utterances were defined by changes of speaking subjects. Hence, the units of analysis for studies of language became a unit of social communication (p. 51).” In this dissertation study, the unit of coding for the discourse analysis is an utterance of a teacher, a student, or students. An utterance begins and ends at a turn-change when the speaker changes. Basically, an utterance is a communication unit such as a question, an answer, a feedback, or a prompt which could be a sentence, a phrase, or sometimes just a word. In this study, when teacher or student talk includes several utterances, each utterance was coded separately.
A Dialogue with Subsidiary Questions and Feedback Questions

Classroom discourse includes several discourse episodes and one discourse episode is determined from when it starts after a classroom activity until it ends when a new classroom activity is initiated. An episode consists of several dialogues between a teacher and students. According to Lemke (1998), Triadic Dialogue is comprised of the teacher’s question, student’s answer and teacher’s evaluation also known as an IRE discourse pattern. Therefore the conversations between a teacher and students can be considered as dialogues although more than one student may participate in that conversation. In the classroom discourse, the dialogues are not always typical IRE patterns; many variations of the patterns occur. For example,

Dialogue 3.1 Teacher Cory 2007-02-26P3

T: Then I get in my car and go to the store; E9 what’s going to happen to the line? Q9.1
SS: It’s going to go up. R9.1
T: It’s going to start getting steeper again. F9.1 Will it go as steep as it did the first leg of the trip? Q9.2
SS: No. R9.2
T: No. F9.2 So I have leg one steep; E9.3 leg two I’m flat, no more distance. E9.4 Leg three I’m going to start going up again. E9.5 Here’s what I want you to think about. P10

Dialogue 3.1 can be considered as extended IRE pattern with the set of a question (Q9.2), a response (R9.2), and a feedback (F9.2) with the explanations (E9.3, 9.4, and 9.5). Some different types of dialogues cannot be defined based on the IRE pattern.
Teachers sometimes use many explanations before or after a question and use various questions even after a question. Although this dialogue has two Question-Response-Evaluation (QRE) patterns, set 9.1 and 9.2, the dialogue includes a portion of teacher’s explanation after the second question and the two patterns are linked by Q9.2 making a longer dialogue. I named the types of questions such as Q9.2 subsidiary questions. In the Dialogue 3.2 below, the teacher extends the dialogue with feedback responding to students’ answers.

Dialogue 3.2 Teacher Cory 2007-02-26P3

T: If I’m on the freeway, what’s my slope going to look like? Q7
S: Down. R7 It’s going to go up in speed. R7.1
T: I’m going to go up in speed. Why? fQ7.2
S: Because [inaudible]. R7.2
T: So what does the slope look like if I gain speed? fQ7.3
S: Steeper. R7.3
T: Pardon? fQ7.4
S: It’s steeper. R7.4
T: It’s steeper. Thank you, Adam. F7.4 What’s going to happen when I get to the grocery store and I stop? Q8

In this dialogue, the feedback-question fQ7.2 and fQ7.3, makes it longer until there is a new question Q8 that starts a new dialogue. In this study, a dialogue is defined as teachers’ and students’ consecutive utterances as they construct the understanding about the question/content. Therefore, in a dialogue, the role of subsidiary Questions and feedback-Questions is critical to form the dialogue’s length, variety, and purpose that
depend on a teacher’s instructional method to lead students’ thinking productively to reach the moment of understanding.

**Length of Dialogue (LOD)**

The features of a dialogue can be identified in the use of *subsidiary questions* and *feedback questions* and the *length of dialogue* (LOD) counted by the number of *turn-changes* in that dialogue. For example, the LOD in Dialogue 3.1 is 4 and the Dialogue 3.2 is 8, counting how often the teacher and students take turns talking in that dialogue. As shown in the example dialogues, a new dialogue starts with a new question. Often teachers repeat the same questions while waiting for a student response or cast a subsidiary question to draw out students’ thinking step-by-step. In this study, a new question was defined as a question that has different answers from the previous question. A repeat of the same question or a subsidiary question with the same answer with as the initial question is not considered as new questions.

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Total Class Time (h:m:s)</th>
<th>Total Episode Time (h:m:s)</th>
<th># of Episodes</th>
<th># of Dialogue</th>
<th>Average LOD</th>
<th>Dialogues/minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cory</td>
<td>3:36:26</td>
<td>1:08:48</td>
<td>9</td>
<td>91</td>
<td>4.15</td>
<td>1.32</td>
</tr>
<tr>
<td>Daisy</td>
<td>7:01:37</td>
<td>1:09:16</td>
<td>10</td>
<td>104</td>
<td>3.97</td>
<td>1.50</td>
</tr>
<tr>
<td>Ann</td>
<td>3:03:09</td>
<td>0:41:21</td>
<td>9</td>
<td>59</td>
<td>4.69</td>
<td>1.40</td>
</tr>
<tr>
<td>Eva</td>
<td>3:34:52</td>
<td>0:57:30</td>
<td>5</td>
<td>31</td>
<td>4.00</td>
<td>0.54</td>
</tr>
<tr>
<td>Ben</td>
<td>4:17:56</td>
<td>1:03:28</td>
<td>6</td>
<td>109</td>
<td>2.38</td>
<td>1.75</td>
</tr>
<tr>
<td>total</td>
<td>21:34:00</td>
<td>5:00:23</td>
<td>39</td>
<td>394</td>
<td>3.68</td>
<td>1.31</td>
</tr>
</tbody>
</table>

*SD = 2.82*
From the Table 3.6, the numbers of episodes and dialogs the teachers have during their 4 or 5 classes and the differences in LOD and dialogue time among them can be gleaned. For example, teacher Ben has an average 2.25 LODs; Ben’s dialogues with students have just about two turn-changes such as teacher question to students’ answer (QR, 1 LOD) and then to teacher feedback (RF, 2 LOD), which is mostly QRE a pattern. However, teacher Ann has an average of 4.79 LODs that indicates her classroom dialogues have almost 5 turn-changes. Ann’s dialogue might often be considered as an extended simple IRE pattern like Q₁R₁FQ₂RF with a subsidiary-question and a feedback-question.

**Levels of Teacher Feedback**

As discussed in Chapter 2, teacher feedback can have positive and negative effects on students’ learning achievement, attitudes, and motivation. The levels of teacher feedback used in this analysis were developed through the literature review of studies on formative feedback: Level 1 – Evaluative, Level 2 – Corrective, and Level 3 – Elaborative feedback (see Table 3.7). Through the data analyses, I have found some exemplars of each level feedback and developed a rubric to clarify what each level of feedback is. In this section, I will introduce the basic concept of each level of feedback and present some examples. Table 3.7 shows the basic principles of classification levels of feedback through the literature review. Determining each level of feedback is challenging but the most fundamental criteria are the main aspects in the Table 3.6. In this study, teachers’ feedback is confined to the teachers’ response to students’ answers or questions.
Table 3.7 Feature of Feedback Levels

<table>
<thead>
<tr>
<th>Level</th>
<th>Main Aspects</th>
<th>Focus</th>
<th>Feedback Content type</th>
<th>Delivery Style</th>
<th>Effects on Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Evaluative, Normative</td>
<td>Student</td>
<td>Grade, Praise, Evaluation, Comparison with others</td>
<td>General comments, No reason, attention to “self”, too long, vague, difficult, or interruptive students’ prompts</td>
<td>No effects</td>
</tr>
<tr>
<td>2</td>
<td>Corrective, Verification</td>
<td>Task</td>
<td>Correction, Right answer, Direct hint, Try again,</td>
<td>Short, clear, fast in written and spoken</td>
<td>Sometimes effective</td>
</tr>
<tr>
<td>3</td>
<td>Elaborative, Facilitative</td>
<td>Task</td>
<td>Location of mistakes, Addressing information, Hint/Cue for the direction, Specific error or misconceptions (what and why)</td>
<td>No correct answers, manageable units for students, considering students’ level, specific and clear, goal orientation, flexible time management</td>
<td>Effective almost always</td>
</tr>
</tbody>
</table>

* Synthesized from the studies of Hattie & Timperley, 2007; Kluger & DeNesi, 1998; Shute, 2008

**Level 1 Feedback**

From the review by Shute (2008), Kluger & DeNesi (1998), and Hattie (2007), the evaluative feedback that provides too general or vague information including praise or evaluation could be ranked level 1, which has no effect or negative effects on students’ learning and performance. Various level 1 feedback also may include wrong information, confusing information, tangential phrases that distract students’ attention, or no responses. If feedback does not consider the students’ level or task level, teachers’ feedback is likely to be level 1. As the name evaluative feedback implies, the basic understanding about this is evaluating students themselves or students’ responses without any specific information and/or reason. However, through the analyses of teachers’ feedback, the boundary of level 1 feedback has been expanded to include vague feedback, comparison with others, wrong information, and direct but irrelevant hints. The Dialogues 3.3, 3.4, and 3.5 are the examples of level 1 feedback.
Dialogue 3.3 Teacher Ann 2007-04-26P1
T: Hello, Cory, is it greater or less? Q1.17
S: Less. R1.17
T: Huh? Exactly; you’re not listening. F1.17

Dialogue 3.4 Teacher Ben 2007-0412P1
T: Well it is related to work. F1 Work and? fQ1.1
S: Amps! R1.1
T: It starts with an “E.” F1.1
S: Electricity! R1.2

Dialogue 3.5 Teacher Ben 2007-04-12P1
T: Number 12. How do you use an ammeter? Q1
S: Oh, I know! R1
T: No actually you do not. F1

In these dialogs, Level 1 feedback usually terminates the conversation in that no additional teacher’s or students’ utterance follows. Many research studies have reported negative effects of Level 1 feedback on students’ learning and motivation (Hattie & Timperley, 2007; Kluger & DeNisi, 1998; Shute, 2008). In addition to the ineffectiveness, the analysis reveals its role in communications efficiently terminate the dialogue.

**Level 2 Feedback**

Shute (2008) classified formative feedback into two categories: verification and elaboration. Verification is the simple information of whether an answer is correct, the most common way involves simply stating “correct” or “incorrect,” with sometimes correct answers as level 2 feedback in this study. On the other hand, elaboration is the
information providing relevant cues to guide the learner toward a correct answer to address the topic, response, particular error, provide worked examples, or guidance as level 3 feedback in this study. With similar ways of classification, Black and William (1998) classified feedback into two categories: directive and facilitative feedback: Providing corrective information and providing guidance and cues (Black & Wiliam, 1998). The researchers all maintained that elaboration/facilitative feedback has more positive effects on students’ performance or learning than verification/directive feedback (Black & Wiliam, 1998; Hattie & Timperley, 2007; Kluger & DeNisi, 1996; Shute, 2008).

The basic description of Level 2 feedback, in this study, is that it provides corrective information without specific information about the reason why. The key difference from Level 1 feedback is providing the simple information of whether an answer is correct; the most common way involves simply stating “correct” or “incorrect.” From the analysis in this study, all the teacher participants use this feedback the most. However, the way teachers deliver the information of correctness may be not “you are right/correct,” but may be repeating students’ answers and saying ‘good’ or ‘nice,’ which can be vague without any following evaluation. Sometimes even with that evaluation, just repeating students’ answers can be vague, and it does not provide any clear information due to the teacher’s various vocal tones. Because of the vagueness, the mere repetition of the students’ responses without any additional positive or negative information belongs to Level 1 feedback.

Questioning can also be one type of feedback, named feedback question in this study. I clarified two types of feedback-questions: one is confirming questions to explicit
students’ answers that are Level 2 feedback; the other is elaborative questions to deepen students’ thinking that is level 3 feedback. The Dialogue 3.6 and 3.7 shows the examples of L2 and L3 feedback questions: Level 2 is fQ7.6 and fQ3.3 and Level 3 is fQ7.7 and fQ7.8.

Dialogue 3.6 Teacher Cory 2007-02-26P1

T: It’s going to… fQ7.5
S: Go down. R7.5
T: Go down? fQ7.6
S: Stay the same. R7.6
T: It’s going to stay the same because what am I no longer doing? fQ7.7
S: You’re not moving. R7.7
T: I’m not moving, but, what’s down here on the X? fQ7.8
S: The time. R7.8

Dialogue 3.7 Teacher Ann 2007-04-26P1

T: what tool do I use to try to measure how I’m going at one particular second? Q3.2
S: Odometer. R3.2
T: What’s that called? fQ3.3
S: Speedometer. Odometer. R3.3

According to the literature, the effects of Level 2 feedback on students’ learning depends on students’ level, task level, or methods of delivering including timing, types of medium (written, spoken, or electronic), simple or sophisticated information (Hattie & Timperley, 2007; Kluger & DeNisi, 1998; Shute, 2008). In this study, the CDAT analysis
shows that the roles of Level 2 feedback for the classroom discourse are various and level 2 feedback is used by all the teachers in the majority of their classes.

**Level 3 Feedback**

Level 3 feedback is the highest level of elaboration responding to students’ answers and questions that could provide relevant cues to guide the learner toward a correct answer to address the topic, response, particular error, provide worked examples, or guidance (Black & Wiliam, 1998; Hattie & Timperley, 2007; Kluger & DeNisi, 1998; Kulhavy et al., 1985; Shute, 2008). Almost all research studies on teacher feedback maintain that this level feedback has a strong positive effect on students’ performance or learning (Black & Wiliam, 1998; Hattie & Timperley, 2007; Kluger & DeNisi, 1996; Shute, 2008). In this study, I could reach more specific clarifications about this level of feedback with clear exemplars. The following dialogue 3.8 includes two level 3 feedback \( F8.7 \) and \( F9.1 \) since they provide the reason and directions to think rather providing information of right or wrong.

**Dialogue 3.8 Teacher Cory 2007-02-26P3**

T: But when I’m not moving, what’s the word you used, Adam? \( Q8.7 \)

S: Flat. \( R8.7 \)

T: The line’s going to be flat because I’m not gaining any more distance, \( F8.7 \) I’m just – the time is still passing. \( E8.8 \) So my distance line is going to stay the same, but time continues. \( E8.9 \) Then I get in my car and go to the store; \( E9 \) what’s going to happen to the line? \( Q9.1 \)

SS: It’s going to go up. \( R9.1 \)

T: It’s going to start getting steeper again. \( F9.1 \)
Certain types of teacher questions can be Level 3 feedback. When a teacher starts a new dialogue, she casts a new question that has a different answer from the previous one. In a dialogue, the teacher can ask subsidiary questions to help the students move toward the answer which can also be feedback questions. The Dialogue 3.8 includes both subsidiary questions and feedback questions.

Dialogue 3.9 Examples of Subsidiary and Feedback Questions

T: So if we went back to slope, what’s our saying for slope? Q1.3 (new) It’s what over what? Q1.4 (subsidiary question)
S: Rise over run. R1.4
T: Rise over run and you would not… F1.4 What’s on our rise this time? fQ1.5 (subsidiary-feedback question)
S: Velocity. R1.5
T: Velocity. F1.5 What’s on our run? Q1.6 (subsidiary question)
SS: Seconds? R1.6 / Time. R1.7 (Teacher Daisy 2008-04-08P5)

**Subsidiary Question vs. Feedback Question**

Distinguishing between subsidiary questions and feedback questions requires careful analysis. In the 3.9 above, Q1.3 is a new question and Q1.4 is a subsidiary question not a feedback question while fQ1.5 could be both a subsidiary and a feedback question. However some feedback questions are not subsidiary questions when asking about students’ thinking such as, “Why is it right?” (Teacher Cory, 2/26/07 p1), or “Ok, so you’re talking about the slant of the line?” (Teacher Ann: 04/27/07 p1). Both types of questions have large positive impacts on the pattern of dialogue by creating longer dialogue on one topic that helps students with their journey to the moment of
understanding. However, subsidiary and feedback questions also have different aspects in their purposes and authentic roles. First, the purpose of feedback questions is to strengthen the desire of the students to create different insights while participating in the provided activities that require them to think more/again. However, a feedback question in this level does not have to trigger high level of cognitive thinking, but rather, might be just a simple question such as ‘why’, ‘how’, or ‘how about ...’, etc. Second, a feedback question is more authentic for students to learn by themselves. With feedback questions, the dialogue can be extended in productive directions to scientific understanding.

On the other hand, the purpose of subsidiary questions is to lead students’ thinking to a certain point on the way to the moment of understanding. Using subsidiary questions requires teachers to be prepared and ready in anticipating the probable answers’ from the students. Subsidiary questions may be very effective and efficient in helping students’ understanding. But on the part of the students, these questions can hinder their own thinking process since the teacher points out what to think.

As shown in Figure 3.2, a question can be clearly classified as a subsidiary question or a feedback question. For example, if a teacher asks students’ thinking like “How do you think like that?” or “Explain more?” then they are clearly feedback questions. However, if a teacher asks about a specific point in the content such as “What is the second aspect of velocity?” then the utterance is a clearly a subsidiary question. However, a question can also be both a subsidiary and feedback question. If a teacher asks “Why do you think speed is different from velocity?” since it asks about both students’ ideas and specific aspects of the content, this question can be either or both.
Therefore, differentiating between these two questions is not always clear or even necessary since both have the same goal that is to lead students in understanding the question and answer. Furthermore, when feedback questions and subsidiary question are combined, the questions might become more specific and productive for students’ scientific understanding. Following are two example dialogues that include subsidiary questions, feedback questions, and sub-feedback questions.

Dialogue 3.10 Examples of Subsidiary, Feedback, and sub-Feedback Qs
(Teacher Ann 2007-04-26P1 w/o CCT)

T: Are you going to go the same speed as you drive to school? \textit{Q2 (new)} What do you do between? \textit{Q2.1(sub)}

SS: Stop. Go. R2.1

T: Stop, at a stop light, and then what do you do? \textit{fQ2.2(sub-feedback)}

S: Go. R2.2

T: You go, and as you start leaving the stop light what do you do? \textit{fQ2.3 (sub-feedback)} As you leave you get a little what? \textit{Q2.4 (sub)}

S: Faster. R2.4
(Teacher Ann 2007-04-20P1 w/o CCT)

T: Does your speed effect the graph? Q6 The straightness of it? Q6.1
S: Yes. R6.1

T: How? How does speed come into play here? fQ6.2 (sub-feedback)
S: Because you’ve got to [inaudible] back. R6.2

**Teachers’ Feedback for Scientific Discourse**

In addition to feedback delivery patterns, the content of feedback should lead the classroom discourse to be scientific. Usually, scientific discourse includes talking of observing, describing, comparing, classifying, analyzing, discussing, hypothesizing, theorizing, questioning, designing experiments, judging, evaluating, generalizing, and discussing in and through the language of science framed by scientific inquiry (Duschl et al., 2007; Lemke, 1998). However, although students talk using the scientific language, their discourse could be scientific or not. To be scientific, the talk should be framed and arranged by scientific reasoning with a specific order due to the purpose of the talk. Therefore, one of a science teacher’s main roles is to scaffold students’ talk by supporting and guiding them to be scientific.

In general classrooms, the basic principles of effective talk with assessment and feedback for student general learning, which can be applied to any subject area, are well known; formative assessment must provide students opportunity to think about the questions “where are we going?,” “where are we now?,” and “what do we need to go there?” and teachers’ feedback must support students to reach the answers for these
questions (Hattie & Timperley, 2007; NRC, 2004). In a science classroom, however, the
questions should be associated with the process of scientific reasoning and teachers’
feedback must help students to attain the answers in a process of scientific reasoning
which is represented as scientific discourse.

**Task Identification: Where to go?**

Scientific reasoning has two basic directions: constructing theories with evidence
(inductive reasoning) and explaining or predicting a phenomenon with models (deductive
reasoning) (Anderson, 2007; NRC, 2004). Therefore, science teachers should be aware of
where the classroom discourse is going and teachers’ feedback must support or redirect
students’ talk in the process to more desirable ways. If students continue to talk about
their experiences, teachers need to prompt them to identify scientific observations or data.

1) Inductive Direction: Prompt to think about observation or data, to find patterns
in the data, to generate a model/hypothesis/theory.

2) Deductive Direction: Prompt to think about related model, theories, or concept,
to generate an explanation with the theory to predict a new phenomenon.

**Assessment: Where am I?**

Teachers’ feedback must help students to recognize where they are or where they
should be in the process of inquiry or reasoning and why. Prompting or asking students to
explain what they are doing is one way revealing where they are, and with appropriate
feedback, teachers’ can provide opportunities to think about why they are doing the task
and what outcome they seek. So, teachers’ feedback helps students gain:
1) Information about what students need to do in terms of collecting observation/data, finding patterns, or constructing models.

2) Information about why they are doing the task.

3) Information about if their thinking and working is scientifically accepted or not.

**Application of Assessment Data: What to do next?**

Acknowledging students where to go as a goal of the lesson must be followed by facilitating their journey. Teachers’ feedback can support students to connect the current step to the next step by scaffolding them to understand the scientific inquiry process. For example, after collecting scientific data, students need to arrange, classify, or synthesize the data by using a table, graph, or diagram to find patterns from the data. Science teachers, therefore, must support or guide them to use timely appropriate scientific skills and tools.

So, teachers’ feedback must help students to find:

1) What outcomes they need.

2) What scientific tools they need.

3) How they connect the outcomes to the next step.

**Conceptual Model of Teacher Feedback with Scientific Reasoning**

Although we cannot measure how well students conceptually understand and develop reasoning skills, the ways teachers’ use feedback or prompts can be examined to assess whether it is scientifically consistent or not (Boyatzis, 1998; Hardy et al., 2010;
Windschitl et al., 2008). The conceptual model shown in Figure 3.3 has been modified from the previous one (Figure 2.1) through the additional literature review and the analysis of the first set of data. Since many scientists also use metaphor and analogy as scientific explanations, metaphor and analogy was replaced by Naïve Explanation (NE) in the model in Figure 3.3.

Figure 3.3 Bridging EDR and SR by TF revised from Anderson, 2007, p. 12 and 18

The conceptual model (Figure 3.3) suggests the effective pathways of transforming students’ reasoning methods, in which the distances between two components in everyday reasoning (ER) or scientific reasoning (SR) represent the relative difficulties of the transformation (Anderson, 2007). This model will help science teachers to figure out where students’ ideas currently belong, what the goal status is, and how to move to the next step. Using this framework for reasoning patterns, teachers can support students in ways that are consistent with formative feedback principles (Hattie & Timperley, 2007; Kluger & DeNisi, 1998; Shute, 2008).
As shown in the model (Figure 3.3), many possible pathways exist which can be directed by teachers’ feedback, but there are effective or ineffective ways as well as the ways which should not be directed. The paths of OD to PD and MT or EX to PE and ME are considered more effective ways to reach to the upper levels because they are already in the same cognitive system. However, paths in only everyday reasoning components are not recommended; rather transferring students’ ideas to scientific components needs to be first. The most recommended way is to start from EX to OD. Teachers must be aware of what students’ experiences are and transfer them to forms of data with measurements and description attributes by doing activities with writing or speaking (Anderson, 2007; Duschl et al., 2007).

**Classroom Discourse Analysis Tool (CDAT)**

A science classroom discourse consists of teacher talk and students’ talk in which the teacher talk could be questions and feedback and students’ talk could be also questions and responses to the teacher question. In a science classroom, a teacher question is usually to assess students’ understanding, but it could be also to scaffold students’ learning as a type of feedback to respond to students’ answers. Teachers’ feedback can have various purposes and methods as discussed above.

Combining two aspects, formative feedback as a method of delivering teachers’ questions and feedback and scientific reasoning to lead students’ thinking, the idea of an analytical tool to assess how teachers’ feedback leads classroom discourse to be scientific was incubated. The CDAT was created by combining teachers’ feedback levels, teachers’
and students’ utterances of questions and answers, and reasoning components in the model (see Figure 3.3). Through the analyses of the first set of data, I combined PE with EX because they are not distinguishable in many cases. Table 3.11 below is a Classroom Discourse Analysis Table (CDAT) with an example dialogue of Dialogue 3.11 coded in CDAT.

**Dialogue 3.11 Teacher Ann 2007-04-26P3 w/o CCT**

T: So what is speed? *Q1* You all should probably be able to tell me that without even having to look at your book because you speed to school every day, right? *Q1.1*

SS: Nope. No. *R1.1*

T: You don’t? Don’t you all ride the school bus? *fQ1.2*

SS: Yes. No. *R1.2*

T: Is speed involved in getting to school? *Q1.3*

S: Yeah. *R1.3*

T: Yeah, what is speed? *Q1.4*

SS: Movement. *R1.4*

T: It’s movement, *f1.4* ok, and what two things do we use to calculate speed? *Q1.5*

SS: Distance traveling over time. *R1.5*

T: Distance traveled over… *fQ1.6*

SS: Time. *R1.6*

<table>
<thead>
<tr>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
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<td><strong>Explaination/Examples</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Question/Prompt</td>
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<td>1,1,4,1,5</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Student Response/Question</strong></td>
<td>1,2,1,3</td>
<td>1,4,1,5,1,6</td>
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<td>1,1</td>
</tr>
<tr>
<td>Feedback</td>
<td>1.3:Elaborative</td>
<td>1.2:Corrective</td>
<td>q1.2</td>
<td>1.4,q1.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

88
CDAT is not for evaluating students’ conceptual understanding or reasoning skills but for tracing teachers’ questioning and feedback. In this section, the basic principles of the coding method will be presented. One goal of this study associated with the first research question is development of an assessment tool for evaluating how scientific science classroom discourse is by examining teachers’ feedback.

**Redefining of Each Reasoning Component (RC)**

CDAT identifies not only the classroom discourse features with LOD and levels of teacher feedback but also how science teachers deal with the phases of scientific reasoning or inquiry during their classroom discourse. CDAT includes seven components of everyday reasoning, knowledge, and scientific reasoning called reasoning components (RC) in this study. With the conceptual framework developed through the literature review, I expect the ideal movements of science classroom discourse such as from students’ experience (EX) to scientific observations and data (OD) and other various scientific movements (see Figure 3.3). In this section, I will present the brief description of each inquiry phase used in this study and provide some examples. I classified the discourse movement first in one dialogue and then among the dialogues presented in this section with examples.

The common components of scientific inquiry are observations/data, patterns, and models/theories to be dealt with when scientists do science as inquiry. In addition, there are five common phases in scientific inquiry as methods or process as of inquiry: questioning, hypothesizing, designing, testing and analyzing, and building theories or predicting phenomena. Those phases are cognitive devices to make connections between
the inquiry components and thinking and doing science. For example, questioning is a scientific thinking activity with observations/data, hypothesizing is a thinking activity with data, patterns, and models, and testing is scientific activity with data, pattern, and models as well. Those inquiry components and phases are controlled and organized by scientific reasoning as a way of scientific thinking. Therefore, learning scientific reasoning is not just practicing a way of thinking but practicing how to deal with those inquiry components and phases in both doing and thinking science. Furthermore, the practices will improve students’ scientific understanding and literacy. In science classrooms, scientific inquiry activities are ways of practicing scientific reasoning. However, without follow up scientific discourse, producing scientific understanding and literacy could be limited (Hackling et al., 2010; Lemke, 1998).

In this study, to examine how teachers foster classroom discourse to be scientific, the CDAT has been used to analyze how science teachers deal with the inquiry components in aspects of scientific reasoning. When inquiry components were mentioned by the teachers, it does not really mean that it is already a scientific discourse. However, using CDAT to analyze classroom discourse can be a gauge on how the teachers form their classroom discourse within the frame of scientific reasoning and inquiry. With CDAT, I also analyzed how the teachers show movements in reasoning components in a dialogue or through dialogues. The following definitions are specified for the coding with CDAT and are unique to this study.
**Scientific Knowledge (SK)**

In this study, Scientific Knowledge (SK) is defined as simple scientific concepts and definitions that teachers want their students to learn. Although scientific knowledge can be considered the same as scientific literacy and is the ultimate goal for students in science education, scientific literacy should be accomplished in the process of inquiry activities and discourse. However, SK still has a big role when students build new understanding by connecting their previous experiences to new experiences and evaluating whether to accept the new learning and integrate it into their scientific understanding. Furthermore, some learning objectives often include basic scientific concepts and definitions that students should learn. Therefore, focusing on SK in classroom discourse does not necessarily identify productive or scientific discourse. When teachers only focus on SK, few connections to students’ previous experiences are provided. New experiences with observations or data in the classroom can help students construct or build SK. For the coding, the utterances of SK are defined as scientific concepts, definitions, equations, or formulas. However, if the utterances have connections to observation/data (OD), they were coded in the OD cell in CDAT. In the Dialogue 3.12, teacher Ben asked only SK questions and did not make any connections with other components in the CDAT.

Dialogue 3.12 Teacher Ben 2007-04-12P1 w/o CCT

T: Okay. One last question. What is joules? Jimmy said joules. What is joules? Ray. Q1

S: Work. R1

T: Well it is related to work. F1 Work and? fQ1.1
S: Amps! R1.1
T: It starts with an “E.” *fQ1.2*
S: Electricity! R1.2

Table CDAT 3.12 Teacher Ben 2007-04-12P1 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>Observation/Data (OD)</th>
<th>Patterns from Data (PD)</th>
<th>Models/Theories (MT)</th>
<th>N/A</th>
</tr>
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<tbody>
<tr>
<td>Explanation/Examples</td>
<td>Ss’ Explanation (NE)</td>
<td>Ss’ Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific knowledge (SK)</td>
<td>Observation/Data (OD)</td>
<td>Patterns from Data (PD)</td>
<td>Models/Theories (MT)</td>
<td>N/A</td>
</tr>
<tr>
<td>Question/Prompt</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Student Response/Question</td>
<td>L3: Elaborative</td>
<td>q1.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>L2: Corrective</td>
<td>q1.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L1: Evaluative</td>
<td>q1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Observation and Data (OD)**

In this study, Observation and Data (OD) is defined as descriptions of natural phenomena or quantified values used as examples or derived from the class inquiry activities. Through the analysis, I found that it is sometimes difficult to distinguish students’ experiences (EX) from ODs since the example observations can start from everyday experiences. In the Dialogue 3.13 below, teacher Ann asked first about students’ experiences (*Q2*), but then she asked the students to think about what they did in that experience and had them explain the situation. So, I classified Q2.1, fQ2.2, fQ2.3, and Q2.4 as questions about OD.

Dialogue 3.13 Teacher Ann 2007-04-26P1 w/o CCT

T: Are you going to go the same speed as you drive to school? *Q2* What do you do between? *Q2.1*
SS: Stop. Go. *R2.1*
T: Stop, at a stop light, and then what do you do? *fQ2.2*
S: Go. *R2.2*
T: You go, and as you start leaving the stop light what do you do? *fQ2.3* As you leave you get a little what? *Q2.4*
S: Faster. *R2.4*
T: You go a little faster. *F2.4* So the average speed is just talking about all your speeds averaged together. *E2.5*

Table CDAT 3.13 Teacher Ann 2007-04-26P1 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
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<td>Explanation/Examples</td>
<td>Ss’ Explanation (NE)</td>
<td>Ss’ Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific knowledge (SK)</td>
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<tr>
<td>Question/Prompt</td>
<td>2</td>
<td>2.1,2.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student Response/Question</td>
<td>L3:Elaborative</td>
<td>2.1,2.2,2.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>L2:Corrective</td>
<td>q2.2,q2.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L1:Evaluative</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Patterns from Data (PD)*

Patterns from Data (PD) include reasoning that involves generalization, comparison, contrasts, relationships, diagrams, graphs, table, computation, categorization, and differentiation. When teachers’ or students’ utterances are not just about OD but also include manipulating the observation/data, they belong to PD in CDAT. Therefore, dealing with tables, graphs, or diagrams are in this category, but if the discourse is just about a graph’s characteristics, definitions, or how to make it without any data then the discourse is categorized as SK. Problem solving with given data is also classified in this category, but if the discourse is only about formulas or how to solve the problem mathematically without any data, then the utterances are coded in the SK category. In the Dialogue 3.14, teacher Cory provides an observation/data from what students did first, E6 and E6.1, and then asked how it appears on the graph as a line, Q6.2 and Q6.3.

Dialogue 3.14 Teacher Cory 2007-02-27P3 w/o CCT

T: Lance, we started here walking. *E6* The CBR was our reference point or our starting point. *E6.1* When we walked from the CBR out across the line, what direction did the line on the graph make? *Q6.2* Did it go up or down? *Q6.3*
T: Up, so it was a positive, so it was true. *F6.3 What did we call it when we come back towards the reference point and the line goes down? *Q7 What’s the opposite of positive, Rashid? *Q7.1
S: Negative. *R7.1
T: Negative. *F7.1

Table CDAT 3.14 Teacher Cory 2007-02-27P3 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
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<tbody>
<tr>
<td></td>
<td>Explanation/Examples (E)</td>
<td>Ss’ Explanation (NE)</td>
<td>Ss’ Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific Knowledge (SK)</td>
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<td>Explanation/Examples (E)</td>
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<td></td>
<td></td>
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<tr>
<td>Question/Prompt (Q)</td>
<td>6,2,6.3,7.1</td>
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<td></td>
<td></td>
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<tr>
<td>Student Response/Question (R)</td>
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<td>6.3,7.1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Feedback</td>
<td>L3:Elaborative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L2:Corrective</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L1: Evaluative</td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Those questions are not asking about if it is faster or slower, but are asking students to make a connection to the movement and the line. That is the main reason why they belong to the PD category. However, if a teacher asks “What’s our saying for slope? It’s what over what?” (Teacher Daisy: 4/7/08 p5), the questions belongs to SK.

**Students’ Experience (EX)**

Questioning or investigating students’ experiences (EX) is really important for students’ learning and is emphasized by many educators especially those holding a constructivists’ view of teaching and learning. As shown in Dialogue 3.15, all kinds of questions, examples, explanations, and feedback about students’ experience (EX) belong to EX in CDAT table. The utterances as experiences (EX) coded in this study were not limited to direct students’ personal experiences but included any kinds of everyday life experiences such as teachers’, from movies, or histories.
T: Time and distance, ok? \textit{F3.1} So really, it’s just a ratio of how far have you gone in a certain amount of time. \textit{E3.2} And you all deal with speed all the time. \textit{E3.3} You all are in baseball, you all are in track, you measure your speed. \textit{E3.4} When you drive to school everyday, roadtrips, when you’re on the Interstate or in your neighborhood. \textit{E3.5}

Table CDAT 3.15 Teacher Ann 2007-04-26P3 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Explanation/Examples</td>
<td>3.3,3,4,3.5</td>
<td>3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Question/Prompt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>L3:Elaborative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L2:Corrective</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L1:Evaluative</td>
<td></td>
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</tr>
</tbody>
</table>

\textit{Naïve Explanation (NE), Model/Theories (MT), and Naïve Knowledge (NK)}

NE is about students’ misconceptions or naïve explanation with their own theories from their experiences. NE can be originated from students’ belief, others’ authorities, common sense, force-dynamic reasoning, or confidence from experiences. Scientists explain/predict natural phenomena with MT, but students’ explanations could be the result of informal reasoning with their own theories. If researchers investigate students’ written discourse such as an assignment, an essay test, or online communication with CDAT, they may find some cases of NE and MT as well as students’ small group discussions or students’ presentations in project based learning.

Naïve Knowledge (NK) has two aspects. First, naive knowledge is a form of common belief, legitimated by commonsensical opinions and not reliant on ‘certainty’ in any scientific sense (Gardiner, 2006). I was planning to code whenever I found students’ or even teachers’ misconceptions or naïve knowledge. However, I realized that
evaluating their knowledge is beyond the scope of this study. Therefore, I chose the second aspect about teachers’ discourse with regards to the misconception or students’ misunderstanding. However, this category almost never appeared in the coded discourse except one case in Teacher Cory’s discourse (see Dialogue 3.15).

Dialogue 3.16 Teacher Cory 2007-02-27P1 w/o CCT

T: The slope. Whew! We know that; good. F3 This is a misconception that many of you – because I kept giving these on your mid summative exams – E3.1 you kept getting the different lines when we looked at the boats – remember the boat races? E3.2 And you saw three different lines. E3.3 A lot of you told me one of the boats was faster because the line was longer. E3.4 Is that true? Q3.5

S: No. R3.5

T: No. F3.5 We can extrapolate and make that line as long as we want on a graph. E3.6 If we want to know the average speed we’re going to look for… Q3.7

S: The slope. R3.7

Table CDAT 3.16 Teacher Cory 2007-02-27P1 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation/Examples</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Question/Prompt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student Response/Question</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>3.1,3.4,3.6</td>
<td>3.2,3.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Scientific Discourse Movement in a Dialogue

One characteristic of the classroom discourse is the total number of teachers’ utterances. On the other hand, the number of utterances in reasoning components can also be a characteristic to gauge if the discourse is scientific or not. In this study, I also examined how many reasoning components the teachers use during their classroom
discourse and what movements they had among the components. For example teacher Ann’s dialogue shows a movement from SK to OD and to PD as below.

Dialogue 3.17 Teacher Ann 2007-04-27P1 w/o CCT

T: What do I mean by constant speed? Q3 You’ll find that on 134. P3.1 What is the constant speed? Q3.2
S: Staying the same? R3.2
T: Yeah. What’s staying the same for a period of time? fQ3.3
S: Speed? R3.3
T: Your speed; constant speed. F3.3 So if you’re going at a constant speed of 50, that means you’re not going to increase or decrease your speed; E3.4 you’re just going to stay the same. E3.5 So if we graph that, you’re going to notice that your graph isn’t going anywhere because you’re going to stay steady at a constant speed. E3.6 You’ll see more what I’m talking about when we get into our lab today. P3.7

Table CDAT 3.17 Teacher Ann 2007-04-27P1 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
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<tbody>
<tr>
<td>Explanation/Examples</td>
<td>Ss’ Explanation (NE)</td>
<td>Ss’ Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific knowledge (SK)</td>
<td>Observation/Data (OD)</td>
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<tr>
<td>Question/Prompt</td>
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<td></td>
<td></td>
<td></td>
<td>3.4,3.5</td>
</tr>
<tr>
<td>Student Response/Question</td>
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<td></td>
<td></td>
<td></td>
<td>3.2,3.3</td>
</tr>
<tr>
<td>Feedback</td>
<td>L3:Elaborative</td>
<td></td>
<td></td>
<td></td>
<td>q3.3</td>
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<tr>
<td></td>
<td>L2:Corrective</td>
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<td>3.3</td>
</tr>
<tr>
<td></td>
<td>L1:Evaluation</td>
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</tbody>
</table>

Movement in Reasoning Components (MRC) Between Dialogues

The discourse movements can occur between dialogues in a discourse episode. The numbers of movement can be counted if a change in reasoning components occurs when the discourse moves on to another dialogue. Movements in reasoning components (MRC) between dialogues can vary such as from SK to OD, SK to EX to OD, or OD to PD when a new dialogue begins. These movements do not tell everything about scientific
discourse, but they can show, at least, how the teacher tries to make connections among components of scientific reasoning or inquiry through the dialogues. Although how to make the connections such as induction, deduction, or inference strongly depends on each teacher’s capacities, how many reasoning components the teachers use could be a gauge of the teacher’s scientific reasoning skills and how close the classroom discourse might be to scientific.

In this chapter, the participants and the data analysis are described. The development of the CDAT along with sample coding example and the coding scheme used in this study are also presented. In chapter 4, the results from CDAT analysis will be presented aligned with the research questions.
Chapter 4: Results

In this study, the classroom discourse analysis table (CDAT) was used to explain the following research questions:

1. How does the analytical tool characterize the classroom discourse with teachers’ questioning and feedback?

2. How does the analytical tool identify how teachers promote scientific classroom discourse?

3. How does the analytical tool identify the difference in discourse between the classroom with CCT and without CCT?

In this chapter, the results from the analyses of 23 instances of science classroom discourse will be presented. All the analyses were done by using CDAT focusing on classroom discourse, teachers’ feedback, and scientific reasoning framed by phases of inquiry. Each teacher’s results will be reported as a case study and comparisons/contrasts of the results from the five teachers’ classroom discourse will be presented as well. The conceptual model takes into account many facets of the classroom discourse analysis and indicates what scientific discourse is by revealing the differences in discourse from the analysis of data from classrooms. The results for each research question raises assertions from the comparisons of the teachers’ discourse and feedback that consists of aspects of scientific reasoning, teachers’ feedback levels, and discourse patterns characterized with length of dialogue and ways of questioning. All the analyses and every comparison
produce various exemplar cases that show the levels of scientific discourse and teachers’ feedback as well as their relationships. These exemplars are combined with the conceptual model to generate implications for teaching and learning science and research studies on science education that uses data from CDAT as dependent or independent variables.

All the results presented here focus on the classroom discourse. The research questions are how CDAT characterizes science classroom discourse focusing on teachers’ questioning and feedback and scientific reasoning. The first research question is about how teachers lead their classroom discourse. The analysis of classroom observations identifies eight aspects about the first question: (1) the amount of time for classroom discourse, (2) length of dialogue (LOD), (3) subsidiary question and feedback question, (4) levels of feedback, (5) students’ utterances and teachers’ utterances, (6) students’ utterances vs. teachers’ feedback, and (7) off topic talk in classroom discourse.

The second research question is about how scientific the classroom discourse is regarding reasoning components identified in the conceptual model (see Figure 3.3). The analysis with CDAT identifies four aspects: (1) use of reasoning components, (2) reasoning movement in a dialogue, (3) reasoning movement among dialogues, and (4) reasoning movement with feedback, questions, and explanations.

The third research question is about how the use of CCT affects how teachers lead classroom discourse (RQ1) and how scientific the classroom discourse is (RQ2). Each result of RQ1 and RQ2 is compared when the teachers used CCT and when they did not.
In this chapter, the results from each teacher’s classroom discourse will be presented first and then the comparisons of each teacher’s results will be presented second for each research question. Finally, some assertions will be suggested with a model that explains how teachers’ questioning and feedback improve students’ learning and scientific discourse.

**RQ1. How do teachers lead classroom discourse?**

Each teacher’s eight aspects of the results about RQ1 will be presented in order: (1) the amount of time for classroom discourse, (2) length of dialogue (LOD), (3) subsidiary question and feedback question, (4) levels of feedback, (5) students’ utterances vs. teachers’ utterances, (6) feedback vs. questions, (7) students’ utterances vs. teachers’ feedback, and (8) off topic talk in classroom discourse.

**Teacher Ann**

Teacher Ann’s school is in a large city area in TX. Her undergraduate major is animal science. She has taught physical science and taught physics content to seventh graders in the observed classrooms. She had 4 years teaching experience when her classes were observed.

**Amount of Time for Discourse**

Four of teacher Ann’s classroom observations were analyzed with CDAT. Table 4.1 shows descriptions of each classroom that includes types of lecture, review, lab, and problem solving and the contents are about speed, average speed, instantaneous speed,
acceleration, and motion graph. Since each class has a lab or problem solving seatwork segment, the class discourse time talking about science content is just about 8 to 12 minutes in each class.

Table 4.1 Teacher Ann’s Classroom Description Observed and Analyzed

<table>
<thead>
<tr>
<th>Class</th>
<th>Class Time (h:m:s)</th>
<th>Class Type</th>
<th>Content</th>
<th>Whole class talk (h:m:s)</th>
<th>Discourse time (m:s)</th>
<th>% of Discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0:59:06</td>
<td>Lecture before PS*</td>
<td>Speed</td>
<td>0:13:53</td>
<td>08:06</td>
<td>13.71</td>
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<tr>
<td>3</td>
<td>0:46:17</td>
<td>Review, Lab, Review</td>
<td>Motion Graph</td>
<td>0:8:38</td>
<td>08:17</td>
<td>17.90</td>
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<tr>
<td>4</td>
<td>0:54:38</td>
<td>Review, Lab, Review</td>
<td>Motion Graph</td>
<td>0:27:01</td>
<td>11:11</td>
<td>20.47</td>
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<tr>
<td>Total</td>
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<td></td>
<td></td>
<td>1:29:11</td>
<td>39:54</td>
<td>18.44</td>
</tr>
</tbody>
</table>

* PS: Problem solving seatwork

**Subsidiary Question and Feedback Question**

One significant finding in this study is the role of teachers’ subsidiary question and feedback question (see details in Chapter 3). Not every longer dialogue is productive or good for students’ understanding but it gives students more opportunity to express their thoughts. As shown in Dialogue and Table CDAT 4.1, teacher Ann uses subsidiary questions and feedback questions as well that provide more opportunities to hear students’ answers and move the dialogue forward productively.

Dialogue 4.1 Teacher Ann 2007-04-27P1 w/o CCT

T: Alright, we have a time graph. *P1.3 What is on our axis?* **Q1.4**
S:  **TS. R1.4**
T:  **T. F1.4** What does the T stand for, probably? **Q1.5**
SS:  Time. **R1.5**
T:  Time. **F1.5** What does the S stand for? **Q1.6**
SS:  Distance. No. **R1.6**
T:  S. **F1.6**
SS:  Speed. **R1.7**
T:  What is speed? **Q1.8**

Table CDAT 4.1 Teacher Ann 2007-04-27P1 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
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<td></td>
<td><strong>Explain</strong> (NE)</td>
<td><strong>S‘ Experience</strong> (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific knowledge (SK)</td>
<td>Observation/ Data (OD)</td>
</tr>
<tr>
<td>Explanation/Examples</td>
<td>Question/Prompt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student Response/Question</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>L3:Elaborative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L2:Corrective</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L1:Evaluate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the dialogue above, teacher Ann casts several *subsidiary questions* (Q1.6 and Q1.8) that make the dialogue longer with more active interactions. While, in the example below (Dialogue 4.2), she uses *feedback questions* (fQ6.2 and fQ6.3). Using *subsidiary* and *feedback questions* increases student’s responses from more students because it gives other students more time to reflect on previous students’ answers and think about what they know or what they understand.

Dialogue 4.2 Teacher Ann 2007-04-27P1 w/o CCT

T:  Does your speed affect the graph? **Q6** The straightness of it? **Q6.1**
S:  Yes. **R6.1**
T:  How? How does speed come into play here? **fQ6.2**
S:  Because you’ve got to [inaudible] back. **R6.2**
T:  You’re got to what? **fQ6.3**
SS: Move back. *R6.3* Move as fast as you can then [inaudible]. *R6.4*

Table CDAT 4.2 Teacher Ann 2007-04-27P1 w/o CCT

<table>
<thead>
<tr>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ss’ Explanation (NE)</td>
<td>Ss’ Experience (EX)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Naive Knowledge (NK)</td>
<td>Scientific knowledge (SK)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Observations/ Data (OD)</td>
<td>Patterns from Data (PD)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Models/Theories (MT)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Explanations/Examples

Question/Prompt

Student Response/Question

Feedback

L3: Elaborative

L2: Corrective

L1: Evaluative

Table 4.2 below shows teacher Ann’s utterances of explanations, questions, feedback, and ratio of level 2 and level 3 feedback and questions counted in her observed classes. She uses more questions than explanations regardless of the type of lessons and provides at least one level 2 and one level 3 feedback.

Table 4.2 Teacher Ann’s Questions and L3 Feedback

<table>
<thead>
<tr>
<th>Class</th>
<th>Episode Type</th>
<th>Episode Time</th>
<th># of Dialogues</th>
<th># of Explanations</th>
<th># of Questions</th>
<th># of L2 Feedback</th>
<th># of L3 Feedback</th>
<th>L2&amp;L3 /Qs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Review PS</td>
<td>4:39</td>
<td>6</td>
<td>21</td>
<td>17</td>
<td>11</td>
<td>2</td>
<td>.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4:06</td>
<td>10</td>
<td>7</td>
<td>24</td>
<td>18</td>
<td>2</td>
<td>.83</td>
</tr>
<tr>
<td>2</td>
<td>Review PS</td>
<td>6:05</td>
<td>10</td>
<td>21</td>
<td>24</td>
<td>15</td>
<td>4</td>
<td>.79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6:15</td>
<td>14</td>
<td>18</td>
<td>25</td>
<td>17</td>
<td>3</td>
<td>.80</td>
</tr>
<tr>
<td>3</td>
<td>Lecture</td>
<td>1:17</td>
<td>5</td>
<td>11</td>
<td>7</td>
<td>2</td>
<td>4</td>
<td>1.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3:38</td>
<td>8</td>
<td>7</td>
<td>19</td>
<td>9</td>
<td>3</td>
<td>.63</td>
</tr>
<tr>
<td>4</td>
<td>Review for a lab</td>
<td>3:20</td>
<td>3</td>
<td>9</td>
<td>7</td>
<td>6</td>
<td>1</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3:40</td>
<td>2</td>
<td>0</td>
<td>25</td>
<td>13</td>
<td>2</td>
<td>.60</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>41:21</td>
<td>59</td>
<td>97</td>
<td>157</td>
<td>101</td>
<td>22</td>
<td>.78</td>
</tr>
</tbody>
</table>
**Length of Dialogue (LOD)**

As discussed in the previous section, as teacher Ann used sub-questions and feedback-questions quite often, the portion of dialogues whose LODs are larger than 2 is about 54% (see Figure 4.1). This means more than half of her dialogues are beyond simple QRE patterns. Moreover, she has a good number of dialogues whose LODs are larger than 7. In those dialogues, students’ answers and teachers’ feedback were interchanged more than seven times on the same topics.

![Figure 4.1 Teacher Ann’s LOD](image)

**Levels of Feedback**

As shown in Figure 4.2 below, teacher Ann mostly used level 2 feedback that provides information about if the students’ answers are right or wrong without any elaboration.
This feedback includes the questions that confirm what students’ answers were. She also uses some amount of level 3 elaborative feedback that provides students with opportunities to think more, cues about the direction to consider, or what they missed in their answers. For example, in the dialogue below, she used two level 3 feedback questions that elaborate students’ answers and point them in a certain direction and encourages them to think more visually instead of just providing the correct information directly.

Dialogue 4.3 Teacher Ann 2007-04-27P3 w/o CCT

T: Ok, what about right here? What did he change? Q2.13 Guys, I’m not talking over you. P2.14 What did he change right here? Raise your hands. Q2.15
S: He walked forward. R2.15
T: He walked forward, F2.15 so what did he change when he started to walk forward? fQ2.16
S: Velocity. R2.16
T: Why, because he changed what about velocity? fQ2.17
S: Direction. *R2.17*

T: Direction, thank you. *F2.17*

Table CDAT 4.3 Teacher Ann 2007-04-27P3 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ss’ Explanation (NE)</td>
<td>Ss’ Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific Knowledge (SK)</td>
<td>Observation/ Data (OD)</td>
</tr>
<tr>
<td>Explanation/Examples</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.14</td>
</tr>
<tr>
<td>Question/Prompt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.13,2.15</td>
</tr>
<tr>
<td>Student Response/Question</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.15,2.16,2.17</td>
</tr>
<tr>
<td>Feedback</td>
<td>L3:Elaborative</td>
<td></td>
<td></td>
<td></td>
<td>q2.16, q2.1</td>
</tr>
<tr>
<td></td>
<td>L2:Corrective</td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>L1:Evaluative</td>
<td></td>
<td></td>
<td></td>
<td>2.15,2.17</td>
</tr>
</tbody>
</table>

Although level 3 feedback does not cover all the dialogues in her classroom discourse but it is still large portion and it works effectively to lead students’ thinking to the answers together. Usually level 3 feedback comes together with level 2 feedback and helps students convince themselves.

*Students’ Utterances vs. Teachers’ Utterances*

In this study, the transcribers hired for the CCMS project transcribed all the talk they could hear from the observation videos. That of course does not mean they recorded all the talk in the classroom, but they recorded almost all the teachers’ and students’ talk when they talk in turns. I counted all their utterances that are usually sentences or phrases depending upon the conversational situations. As shown in Figure 4.3, in teacher Ann’s classroom discourse, teacher’s talk is about 65% and students’ talk occupies 25% of the total number of utterances except off-topic talk (N/A). Students’ talk is usually answers to the questions the teacher asked.
Teachers usually have three types of turns to talk in questioning, explaining, and feedback in a classroom discourse. Students, however, often only have a turn for answering but they sometimes fail to answer in their turns. In teacher Ann’s classroom, students answered almost all the teachers’ questions and many of the responses were from more than two students.

Off Topic Talk (N/A)

Off topic talk coded as N/A are the utterances that are not relevant to the topic. These utterances were mostly talk to manage or discipline students’ behaviors during the discourse dialogues. In her classroom, teacher Ann devotes only a small portion of her talk to N/A (see Figure 4.3). Her students listened to well and engaged in the discourse with her almost all the time; they did not talk privately and without the teacher’s permission.
Teacher Ben

Amount of Time for Discourse

Five of teacher Ben’s classroom observations were analyzed with the CDAT. Since teacher Ben teaches in a block schedule, one class lasts 1.5 hours. As shown in Table 4.3, the class topics are electric current, electric energy, power, and motors. The types of classes are reviews of problem solving, lectures about principles of motors, and speed versus frequency. His lecture in the first class took almost thirty minutes, a big portion of the discourse time. In other classes, teacher Ben’s discourse time was much less than in the first class since he spent the class time explaining how to do the experiment and disciplining the students’ behaviors before and after a lab activity and seatwork.

Table 4.3 Teacher Ben’s Classroom Description Observed and Analyzed

<table>
<thead>
<tr>
<th>Class</th>
<th>Class Time (h:m:s)</th>
<th>Class Type</th>
<th>Content</th>
<th>Whole class talk (h:m:s)</th>
<th>Discourse time (h:m:s)</th>
<th>% of Discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1:14:11</td>
<td>Review after PS*, lecture</td>
<td>Electric Current, Electric Energy</td>
<td>0:46:00</td>
<td>0:32:12</td>
<td>43.41</td>
</tr>
<tr>
<td>2</td>
<td>1:30:00</td>
<td>Review before a lab</td>
<td>Electric Power, Motor</td>
<td>0:18:47</td>
<td>0:03:11</td>
<td>3.54</td>
</tr>
<tr>
<td>3</td>
<td>1:24:43</td>
<td>Review before a lab</td>
<td>Electric Power, Motor</td>
<td>0:25:50</td>
<td>0:13:02</td>
<td>15.38</td>
</tr>
<tr>
<td>4</td>
<td>1:27:08</td>
<td>Review after PS</td>
<td>Speed vs. Frequency</td>
<td>0:25:08</td>
<td>0:05:46</td>
<td>6.62</td>
</tr>
<tr>
<td>5</td>
<td>1:25:35</td>
<td>Review after PS</td>
<td>Speed vs. Frequency</td>
<td>0:20:56</td>
<td>0:09:17</td>
<td>10.58</td>
</tr>
<tr>
<td>Total</td>
<td>7:01:37</td>
<td></td>
<td></td>
<td>2:16:41</td>
<td>1:03:28</td>
<td>15.02</td>
</tr>
</tbody>
</table>

* Problem solving seatwork
Subsidiary Question and Feedback Question

Teacher Ben does not use either subsidiary questions or feedback questions and that makes the LOD in his classes usually less than two.

Dialogue 4.4 Teacher Ben 2007-04-12P1 w/o CCT

T: Number 8 --what flows in the water? Q2
S: Electricity? I do not know. R2
T: Okay. Electricity would be correct so I cannot say it is wrong. F2 What flows in water, Curt? Q3
S: Current. R3
T: Current very good! F3 Ed, what floats in the water? Q4
S: Electrons. R4
T: Electrons, very good! R4 There is one more I can think of. Megan. Q5
S: Amps. R5
T: Amps is current. Very good! F5 Kate. Q6

Table CDAT 4.4 Teacher Ben 2007-04-12P1 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation/Examples</td>
<td>Ss' Explanation (NE)</td>
<td>Ss' Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific knowledge (SK)</td>
<td>Observation Data (OD)</td>
</tr>
<tr>
<td>Question/Prompt</td>
<td></td>
<td></td>
<td>2,3,4,5,6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student Response/Question</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>1.3: Elaborative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2: Corrective</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.1: Evaluative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the Dialogue 4.4, teacher Ben repeatedly asked exactly the same questions to other students without any connections from the previous students’ answers. Therefore, these questions are not subsidiary- or feedback questions but they can be considered as new questions that starts a new dialogue.
**Dialogue 4.5 Teacher Ben 2007-04-12P1 w/o CCT**

T: What does an ammeter do? *Q3*
S: Measures volts? *R3*
S: Amps? *R3.1*

T: Amps. Ammeter think amps; current. *F3.1*
S: I know. I thought we said amps. *R3.2*
T: Allright. How do you use a voltmeter? *Q4*
S: Amps. *R4*
S: I know this one. *R4.1*

T: You do not turn it on. Do you want to try it? *P4.2*
S: What is a voltmeter? *qR4.3*

T: What you do it. You turn it on where? *F4.3*
T: How is it wired Nolan, in a series or parallel? *Q5*
S: Parallels? *R5*
T: Parallels. *F5*
S: I am a genius! *R5.1*

T: Did everybody get that one? *fQ5.1* Voltmeter is wired in parallel. *E5.2* Okay here is one. Number 18. *P6*

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation/Examples</td>
<td><em>S</em>’s Explanation (NE)</td>
<td><em>S</em>’s Experience (EX)</td>
<td>Naïve Knowledge (NK)</td>
<td>Scientific Knowledge (SK)</td>
<td>Observations' Data (OD)</td>
</tr>
<tr>
<td>Question/Prompt</td>
<td>5.2</td>
<td>3.4,5</td>
<td>3.3,1,4,04,3.5</td>
<td>3.2,4,1</td>
<td></td>
</tr>
<tr>
<td>Student Response/Question</td>
<td>3.3,1,4,04,3.5</td>
<td>3.1,5,05.1</td>
<td>4.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>L3: Elaborative</td>
<td>L2: Corrective</td>
<td>L1: Evaluative</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the Dialogue 4.5, the teacher’s pattern of questioning is the same as in the previous Dialogue 4.4. As shown in the two example dialogues, his feedback is almost all level 1 and level 2 feedback like the feedback fQ5.1 and F4.3. Since the feedback F4.3 is not clearly related to the student’s question, it is considered as level 1 feedback. Almost
all the LODs of the dialogues in his classes are less than 2 with level 1 and level 2 feedback in his dialogues.

Table 4.4 below shows the numbers of teacher Ben’s utterances in explanations, questions, feedback, and ratio of level 2 and level 3 feedback to teacher’s questions (Qs) counted in his observed classes. In the fourth and fifth classes he used quick poll (QC) for the problem solving with just one question and he read all the students’ answers without any comments about their answers until the last answer. And then he had the students vote to pick the best answers, which are all counted as level 1 feedback. After voting for the best answer, he gave an explanation about the answer without any interaction with the students. The ratio of L2 and L3 feedback to teacher’s questions (Qs) is about .42. Teacher Ben did not provide meaningful feedback nor did he receive students’ responses as often as he asked questions.

Table 4.4 Teacher Ben’s Questions, Explanations, and Feedback

<table>
<thead>
<tr>
<th>Class</th>
<th>Episode Type</th>
<th>Episode Time</th>
<th># of Dialogues</th>
<th># of Explanations</th>
<th># of Questions</th>
<th># L2 Feedback</th>
<th># L3 Feedback</th>
<th>L2&amp;L3 /Qs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Review after PS, lecture</td>
<td>16:53</td>
<td>28</td>
<td>20</td>
<td>53</td>
<td>33</td>
<td>3</td>
<td>.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8:52</td>
<td>7</td>
<td>23</td>
<td>16</td>
<td>11</td>
<td>0</td>
<td>.69</td>
</tr>
<tr>
<td>2</td>
<td>Review before a lab</td>
<td>3:11</td>
<td>3</td>
<td>20</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>.00</td>
</tr>
<tr>
<td>3</td>
<td>Review before a lab</td>
<td>7:43</td>
<td>20</td>
<td>12</td>
<td>20</td>
<td>9</td>
<td>2</td>
<td>.55</td>
</tr>
<tr>
<td>4</td>
<td>Review after PS</td>
<td>5:46</td>
<td>25</td>
<td>13</td>
<td>25</td>
<td>2</td>
<td>0</td>
<td>.08</td>
</tr>
<tr>
<td>5</td>
<td>Review after PS</td>
<td>9:17</td>
<td>26</td>
<td>16</td>
<td>27</td>
<td>1</td>
<td>0</td>
<td>.04</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>7:01:37</td>
<td>109</td>
<td>104</td>
<td>143</td>
<td>56</td>
<td>5</td>
<td>.43</td>
</tr>
</tbody>
</table>
**Length of Dialogue (LOD)**

As discussed in the previous section, teacher Ben does not use subsidiary questions and feedback questions often; thus, the portion of dialogues whose LODs are less than 3 is almost 80% (see Figure 4.4). Most of the dialogues in his classes are simple QRE patterns. Notably, the dialogues that have only 1 or 0 LODs make up almost 20% (see Figure 4.4). Zero LOD means that the teacher did not receive any responses from his students and one LOD means the teacher did not provide any feedback for the students’ answers.

![Figure 4.4 Teacher Ben’s Length of Dialogue (LOD)](image)

**Levels of Feedback**

As shown in Figure 4.5 below, teacher Ben’s percentage of level 1 feedback represents more than half of his classroom feedback (52%). He provided vague,
evaluative, comparative, or irrelevant responses as feedback. He rarely used level 3 feedback as well as feedback questions and subsidiary questions. L1 and L2 feedback usually terminate the dialogue quickly resulting in relatively short dialogues as shown in Figure 4.4.

Figure 4.5 Teacher Ben’s Feedback

**Students’ Utterances vs. Teachers’ Utterances**

During teacher Ben’s classroom discourse, there were many off topic conversations which were counted as N/A utterances between the teacher and students (see Figure 4.6 below). Because of the classroom circumstances, the teacher usually did not listen or collect students’ answers in a timely manner and the teacher could not provide appropriate feedback, since he failed to construct timely appropriate discourse patterns. One reason for the relatively high ratio of teacher’s and students’ utterances is that he had many dialogues whose LOD is 2, which is a simple QRE pattern.
Teacher Cory

Amount of Time for Discourse

Four of teacher Cory’s classroom discourse episodes were analyzed with CDAT. Table 4.10 shows descriptions of each classroom that includes types of lecture such as review, lab, and problem solving with topics including speed, complex motion, and motion graphs. She spends more than 30% of the class time talking about the content she taught before/after problem solving seatwork, a lab, and a demonstration. Her whole class talk including discourse time is almost the same as the time the students spent for seatwork or a lab; total class talk time is about half of the total class time (see Table 4.5) and other half was spent for seatwork or lab activities.
Table 4.5 Teacher Cory’s Classroom Description Observed and Analyzed

<table>
<thead>
<tr>
<th>Class</th>
<th>Class Time (h:m:s)</th>
<th>Class Type</th>
<th>Content</th>
<th>Whole class talk (h:m:s)</th>
<th>Discourse time (h:m:s)</th>
<th>% of Discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0:44:35</td>
<td>Review PS*, Lecture</td>
<td>Speed, Complex motion</td>
<td>0:32:57</td>
<td>0:25:59</td>
<td>58.28</td>
</tr>
<tr>
<td>2</td>
<td>0:42:14</td>
<td>Review PS, Lecture</td>
<td>Speed, Complex motion, Motion Graph</td>
<td>0:23:29</td>
<td>0:10:00</td>
<td>23.68</td>
</tr>
<tr>
<td>3</td>
<td>0:54:15</td>
<td>Review PS Review Lab</td>
<td>Complex motion, Motion Graph</td>
<td>0:27:16</td>
<td>0:18:08</td>
<td>33.43</td>
</tr>
<tr>
<td>4</td>
<td>0:42:05</td>
<td>Review after a lab</td>
<td>Complex motion, Motion Graph</td>
<td>0:24:01</td>
<td>0:14:41</td>
<td>34.89</td>
</tr>
<tr>
<td>Total</td>
<td>3:03:09</td>
<td></td>
<td></td>
<td>1:47:43</td>
<td>1:08:48</td>
<td>37.56</td>
</tr>
</tbody>
</table>

* PS: Problem solving seatwork

Subsidiary Question and Feedback Question

Teacher Cory does use many subsidiary questions and feedback questions that make her classroom discourse much longer than a simple QRE pattern. For example, in the Dialogue 4.6 below, the teacher uses several feedback questions to draw students’ answers without giving them the right answers (see Table CDAT 4.6 below). Therefore, the LOD of the dialogue becomes extended but the teacher and her students move forward together.

Dialogue 4.6 Teacher Cory 2007-02-26P1 w/o CCT

T: So I have leg one here where I have a pretty good distance. E7.1 Then I’m going to get to Giant Eagle. E7.2 This is the second leg of my trip. E7.3 What’s going to happen here to my motion? Q7.4

S: The line [inaudible]. R7.4

T: It’s going to… fQ7.5

S: Go down. R7.5

T: Go down? fQ7.6
S: Stay the same. \textit{R7.6}
T: It’s going to stay the same because what am I no longer doing? \textit{fQ7.7}
S: You’re not moving. \textit{R7.7}
T: I’m not moving, but, what’s down here on the X? \textit{fQ7.8}
S: The time. \textit{R7.8}
T: Does time still pass when I’m at Giant Eagle, or does time stop, too? \textit{fQ7.9}
S: It still passes. \textit{R7.9}
T: It’s still going. \textit{F7.9} So my distance isn’t going to change. \textit{E7.10} My distance is going to stay… \textit{fQ7.11}
S: The same. \textit{R7.11}
T: The same. \textit{F7.11}

Table CDAT 4.6 Teacher Cory 2007-02-26P1 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ss’ Explanation (NE)</td>
<td>Ss’ Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific knowledge (SK)</td>
<td>Observation/ Data (OD)</td>
</tr>
<tr>
<td>Explanation/Examples</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.1,7.2,7.3,</td>
</tr>
<tr>
<td>Question/Prompt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.4</td>
</tr>
<tr>
<td>Student Response/Question</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.4,7.5,7.6,</td>
</tr>
<tr>
<td>Feedback</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.11</td>
</tr>
<tr>
<td>1.3:Elaborative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.11</td>
</tr>
<tr>
<td>1.2:Corrective</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.11</td>
</tr>
<tr>
<td>1.1:Evalative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.11</td>
</tr>
</tbody>
</table>

In the Dialogue 4.7 below, teacher Cory uses several subsidiary questions distinguished from feedback questions but they have almost the same functions in that dialogue to extend the discourse as well as students’ thought. The question 3.6 and 3.7 are not feedback questions but they are connected to the first question 3.4 and helped the students to understand more clearly and deeply.
Dialogue 4.7 Teacher Cory 2007-02-27P1 w/o CCT

T: And you saw three different lines. E3.2 A lot of you told me one of the boats was faster because the line was longer. E3.3 Is that true? Q3.4

S: No. R3.4

T: No. F3.4 We can extrapolate and make that line as long as we want on a graph. E3.5 If we want to know the average speed we’re going to look for… Q3.6

S: The slope. R3.6

T: The slope. F3.6 Give me another word for that slope. We’re looking at the… Q3.7

S: Line? R3.7

T: How it’s what? fQ3.8

S: Inclined? R3.8

T: How steep it is, good. F3.8

Table CDAT 4.7 Teacher Cory 2007-02-27P1 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation/Examples</td>
<td>3.3</td>
<td></td>
<td>3.2,3.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Question/Prompt</td>
<td>3.4</td>
<td></td>
<td></td>
<td>3.6,3.7</td>
<td></td>
</tr>
<tr>
<td>Student Response/Question</td>
<td>3.4</td>
<td></td>
<td></td>
<td>3.6,3.7,3.8</td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>L3:Elaborative</td>
<td>q3.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L2:Corrective</td>
<td>3.4</td>
<td>3.6,3.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L1:Evaluative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the Dialogue 4.7 above, Q3.6 and Q3.7 are classified as sub-questions because they are not responding to the previous students’ answers, but rather they are related to the first question 3.4. On the other hand, question 3.8 is directly responding to the student’s answer so it is categorized as a feedback question.

Table 4.6 below shows teacher Cory’s utterances of explanations, questions, feedback, and ratio of level 2 and level 3 feedback vs. questions counted in her observed classes. In all the episodes, the numbers of questions are much larger than the number of dialogues; that means she used many subsidiary questions. Furthermore, she provides L3
feedback remarkably in addition to L2 feedback. The ratio L2 and L3 feedback to teacher’s questions (Qs) is 1.21. She provided more feedback than questions which means that she possibly receives more than one response from her students for the same question.

Table 4.6 Teacher Cory’s Questions and L3 Feedback

<table>
<thead>
<tr>
<th>Class</th>
<th>Episode Type</th>
<th>Episode Time</th>
<th># of Dialogues</th>
<th># of Explanations</th>
<th># of Questions</th>
<th># of L2 Feedback</th>
<th># of L3 Feedback</th>
<th>L2&amp;L3 /Qs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Review PS*, Lecture</td>
<td>6:51:60:09</td>
<td>12</td>
<td>10</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>Review PS, Lecture</td>
<td>2:46:6:17</td>
<td>16</td>
<td>10</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>Review PS, Review Lab</td>
<td>4:53:13:15</td>
<td>5</td>
<td>10</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>Review after a lab</td>
<td>7:26:7:15</td>
<td>11</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1:08:48</td>
<td>91</td>
<td>214</td>
<td>156</td>
<td>119</td>
<td>69</td>
<td>1.21</td>
</tr>
</tbody>
</table>

* Problem Solving Seatwork

**Length of Dialogue (LOD)**

As discussed in the previous section, teacher Cory uses many sub- and feedback questions which are reflected by the percentages (> 73%) of LODs that are greater than three (see Figure 4.7). More than two thirds of the dialogues in her classroom discourse are beyond the simple QRE patterns, which have larger than 3 LODs (Figure 4.7).
Levels of Feedback

As shown in Figure 4.8 below, teacher Cory never used level 1 feedback; instead she uses a larger amount of level 3 elaborative feedback. She also has considerable level 2 feedback but almost half are coupled with level 3 feedback. In the Dialogue 4.8 below, fQ3.3 is a L3 feedback and the L2 feedback F3.3 follows after the student’s answer.

Dialogue 4.8 Teacher Cory 2007-02-26P1

S: It’s wrong. R3 It’s right. R3.1 It’s right. R3.2
T: Why is it right, Ryan? fQ3.3
S: The slash means per. R3.3
T: The slash means per, good. F3.3
Students’ Utterances vs. Teachers’ Utterances

Teacher Cory’s classroom is also well organized and her students actively participated in the classroom discourse. The ratio of students’ utterances to teacher’s utterances is relatively high (.47) as shown in Figure 4.9 below. She often drew students’ responses during a dialogue by using subsidiary questions and feedback questions. N/A utterances filled about 10% of her discourse, which were often used to engage students in the discourse.
In her classroom discourse, 10% of N/A utterances seemed not to interfere with the didactic interactions between the teacher and students during the dialogue. Although some N/A utterances were disruptive, N/A utterances between the teacher and students often made the classroom circumstances more productive by making some fun, encouraging students to engage, or competing with other students in teacher Cory’s classroom discourse.

**Teacher Daisy**

**Amount of Time for Discourse**

Five of teacher Daisy’s classroom discourse episodes were analyzed with CDAT. Table 4.7 shows brief descriptions of teacher Daisy’s analyzed classes that include types of classes and the science content dealt with. She clearly spent more time to talk during a
lecture explaining some contents and less time to talk in other types of instructions such as a lab, problem solving seatwork, or a review.

In classes 4 and 5, students did seatwork with a quiz for more than half of the class time. Before and after the quiz, the teacher talked much about the logistics of quiz taking but not about the science content in the quiz. That is the reason why there is just a small amount of discourse portion in those classes.

**Subsidiary Question and Feedback Question**

Teacher Daisy also uses many subsidiary questions and feedback questions in her dialogues with students. However, most of the subsidiary and feedback questions in her dialogues are of the examples that have both aspects; responding to students’ answers as well as giving questions that make the students’ thinking move toward understanding. In the Dialogue 4.9 below, the questions fQ4.1, fQ4.4, and fQ4.6 are responses to students’

### Table 4.7 Teacher Daisy’s Classroom Description Observed and Analyzed

<table>
<thead>
<tr>
<th>Class</th>
<th>Class Time (h:m:s)</th>
<th>Class Type</th>
<th>Content</th>
<th>Whole class talk (h:m:s)</th>
<th>Discourse time (h:m:s)</th>
<th>% of Discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0:28:21</td>
<td>Lecture, Review before a lab, Lab</td>
<td>Acid and Bases</td>
<td>0:20:03</td>
<td>0:12:24</td>
<td>43.74</td>
</tr>
<tr>
<td>2</td>
<td>0:44:42</td>
<td>Lecture Review after a lab</td>
<td>Speed, Velocity, Motion Graph</td>
<td>0:29:25</td>
<td>0:23:42</td>
<td>53.02</td>
</tr>
<tr>
<td>3</td>
<td>0:49:33</td>
<td>Lecture, Review after PS* and a lab</td>
<td>Velocity, Acceleration, Motion Graph</td>
<td>0:28:26</td>
<td>0:25:26</td>
<td>51.33</td>
</tr>
<tr>
<td>4</td>
<td>0:46:31</td>
<td>Review before/ after PS</td>
<td>Complex motion, Motion Graph</td>
<td>0:12:05</td>
<td>0:03:01</td>
<td>6.49</td>
</tr>
<tr>
<td>5</td>
<td>0:45:45</td>
<td>Review before/ after PS</td>
<td>Distance Graph</td>
<td>0:17:06</td>
<td>0:04:43</td>
<td>10.31</td>
</tr>
<tr>
<td>Total</td>
<td>3:34:52</td>
<td></td>
<td></td>
<td>1:47:05</td>
<td>1:09:16</td>
<td>32.24</td>
</tr>
</tbody>
</table>

*PS: Problem solving seatwork
answers while the questions Q4.2, Q4.3, Q4.7, and Q4.9 are subsidiary questions that are connected to the first question Q4. However, all the questions in this dialogue except Q4 can be considered either a subsidiary or a feedback question and they do not need to be distinguished, but rather can be called sub-feedback questions.

Dialogue 4.9 Teacher Daisy 2008-04-06P8 w/o CCT

T: What’s the little saying, something over something determines our slope? Q4
SS: Rise over run. R4
T: Rise over run. Good. F4 In this graph what’s our rise? fQ4.1 What’s our Y axis? Q4.2 What’s the label? Q4.3
SS: Distance. R4.3
T: Distance, good. F4.3 What’s on our run? fQ4.4
T: Seconds which is measured…fQ4.6
SS: Time. R4.6
T: Time, good. F4.6 And what is distance divided by time? Q4.7
SS: Velocity. R4.7 Speed. R4.8
T: Speed, F4.8 and then to make it velocity what do we have to tack on? Q4.9
SS: Direction. R4.9
T: Right. Allright, F4.9

Table CDAT 4.9 Teacher Daisy 2008-04-06P8 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation/Examples</td>
<td>Ss’ Explanation (NE)</td>
<td>Ss’ Experience (EX)</td>
<td>Naïve Knowledge (NK)</td>
<td>Scientific knowledge (Sk)</td>
<td>Observation/Data (OD)</td>
</tr>
<tr>
<td>Question/Prompt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4, 4, 7, 4, 9</td>
</tr>
<tr>
<td>Student Response/Question</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4, 4, 7, 4, 8, 9</td>
</tr>
<tr>
<td>Feedback</td>
<td>L3: Elaborative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L2: Corrective</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L1: Evaluative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In the Dialogue 4.10 below, teacher Daisy also uses the same questioning pattern with sub-feedback questions. The questions Q7.2, fQ7.3, and Q7.4 can be considered as either subsidiary or feedback questions. They have a common function to extend the dialogue and their own specific aspects; the former are connected questions to the initial question and the latter is a response to students’ answers.

Dialogue 4.10 Teacher Daisy 2008-04-06P5 4.10 w/o CCT

T: So now let’s think about this middle section here. P7 So the car is about two and a half meters at this specific point. E7.1 How far away is the car at this point over here on the right side? Q7.2

S: Two and half meters. R7.2

T: Two and a half meters F7.2 so if we were at two and a half meters here and we’re still at two and a half meters here, was the car moving? fQ7.3

SS: No. R7.3

T: No, F7.3 so what could we say the velocity was when we had our line go flat? Q7.4

S: Zero. R7.4

T: Zero. F7.4 The car was not moving, therefore there’s no velocity. E7.5

Table CDAT 4.10 Teacher Daisy 2008-04-06P5 4.10 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>So Explanation (NE)</td>
<td>So’ Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific Knowledge (SK)</td>
<td>Observation/Data (OD)</td>
</tr>
<tr>
<td>Explanation/Examples</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.1</td>
</tr>
<tr>
<td>Question/Prompt</td>
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<td></td>
<td></td>
<td></td>
<td>7.7.2</td>
</tr>
<tr>
<td>Student Response/Question</td>
<td>L3:Elaborative</td>
<td></td>
<td></td>
<td></td>
<td>7.2,7.3</td>
</tr>
<tr>
<td>Feedback</td>
<td>L2:Corrective</td>
<td></td>
<td></td>
<td></td>
<td>q7.3</td>
</tr>
<tr>
<td></td>
<td>L1:Evaluative</td>
<td></td>
<td></td>
<td></td>
<td>7.2,7.3</td>
</tr>
</tbody>
</table>

Table 4.8 below shows teacher Daisy’s utterances of explanations, questions, feedback, and ratio of level 2 and level 3 feedback vs. questions counted in her observed classes. During the lecture time in the classes 1 and 2, she provided many explanations,
but she also did much questioning with subsidiary questions. Although her level 3 feedback numbers are not high, using many subsidiary questions has the similar functions of using L3 feedback in that they extend the dialogues and lead students’ thinking toward understanding the answers.

Table 4.8 Teacher Daisy’s Questions and L3 Feedback

<table>
<thead>
<tr>
<th>Class</th>
<th>Episode Type</th>
<th>Episode Time(h:m:s)</th>
<th># of Dialogues</th>
<th># of TEx*</th>
<th># of Questions</th>
<th># of L2 Feedback</th>
<th># of L3 Feedback</th>
<th>L2&amp;L3 /Qs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lecture, Review before a lab, Lab</td>
<td>6:36</td>
<td>18</td>
<td>34</td>
<td>28</td>
<td>27</td>
<td>5</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5:48</td>
<td>3</td>
<td>0</td>
<td>21</td>
<td>5</td>
<td>0</td>
<td>0.24</td>
</tr>
<tr>
<td>2</td>
<td>Lecture, PS* together after a lab</td>
<td>13:46</td>
<td>24</td>
<td>58</td>
<td>57</td>
<td>38</td>
<td>2</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7:34</td>
<td>9</td>
<td>14</td>
<td>29</td>
<td>20</td>
<td>4</td>
<td>0.83</td>
</tr>
<tr>
<td>3</td>
<td>Lecture, PS* together after a lab</td>
<td>16:25</td>
<td>17</td>
<td>32</td>
<td>56</td>
<td>35</td>
<td>2</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9:01</td>
<td>11</td>
<td>23</td>
<td>27</td>
<td>28</td>
<td>10</td>
<td>1.41</td>
</tr>
<tr>
<td>4</td>
<td>Review before/ after PS</td>
<td>1:08</td>
<td>2</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:53</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>8</td>
<td>0</td>
<td>1.60</td>
</tr>
<tr>
<td>5</td>
<td>Review before/ after PS</td>
<td>0:56</td>
<td>3</td>
<td>8</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1.50</td>
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<tr>
<td></td>
<td></td>
<td>3:45</td>
<td>10</td>
<td>11</td>
<td>10</td>
<td>12</td>
<td>0</td>
<td>1.20</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1:09:16</td>
<td>104</td>
<td>193</td>
<td>239</td>
<td>178</td>
<td>24</td>
<td>0.85</td>
</tr>
</tbody>
</table>

* Teacher explanations

**Length of Dialogue (LOD)**

As discussed in the previous section, teacher Daisy uses many subsidiary questions so more than half of the dialogues are longer than 2 LODs (see Figure 4.10) which means the dialogues are much beyond simple QRE patterns.
Figure 4.10 Teacher Daisy’s LOD

Levels of Feedback

As shown in Figure 4.11 below, teacher Daisy’s feedback is almost all level 2. However, as discussed before, she used many subsidiary questions that usually come with L2 feedback.

Figure 4.11 Teacher Daisy’s Feedback
Students’ Utterances vs. Teachers’ Utterances

Teacher Daisy’s classroom is also well organized and her students actively participated in the classroom discourse. Figure 4.12 below illustrates Daisy’s classroom utterances. The reason for the high percentage of N/A utterances is the activities with CCT during the problem solving episodes. During a point activity when students controlled individual and uniquely shaped cursors, much irrelevant students’ talk arouse. However, the classes were well managed and she often waited while the students were figuring out what they have to do with the technology and put their answers on their own calculators. Since the irrelevant students’ utterances occurred during the waiting time, at first I thought that these utterances should not be counted. However, on second thought, I recorded them as N/A students’ utterances because they occurred during the dialogues.

Figure 4.12 Teacher Daisy’s Utterances

ratio of students' to teacher's = .40
Teacher Eva

Amount of Time for Discourse

Five of teacher Eva’s classroom discourse episodes were analyzed with the CDAT. Table 4.9 shows descriptions of each classroom that includes types of class such as a review, problem solving seatwork, and a lab. Teacher Eva showed various waves on a projector screen and had the students pick a phase or wave that she asked them to find. Students used their handheld calculator that is connected to the teacher’s computer to move their own unique cursors on the screen. During the activity, the teacher waited after a question for about 1 or 2 minutes and the students spent time figuring out the questions and where their cursors were, and moving their cursors. With the activities, the classroom discourse time increased but LODs were not increased as discussed in the next section. The positive aspects of using this activity are: first, it provides wait time to the teacher, and second, it adds fun on the part of the students. However, this activity can be also distractive, when some students just followed other students’ cursors and used class time for serial interaction rather than learning. The classroom observations analyzed in this study are two and three periods in two different classes (see Table 4.9 below). The classes 1 and 2 had a lab activity that the students spent most of the class time. In the classes 3, 4, and 5, the students completed the same lab activity and they had follow up quiz time as reviews of the lab activity. Thus, the class discourse time increased in the later classes.
### Subsidiary Question and Feedback Question

Teacher Eva’s discourse dialogues are usually simple QRE patterns, but she added an additional QRE pattern with one feedback or subsidiary question. As shown in the Dialogue 4.11 below, the teacher repeated the same question several times while she was waiting for the class response (CR3) and students produced much irrelevant talk (see Figure 4.12). Therefore, the actual dialogue was quite long but the core didactic dialogue is relatively short from Q3.18 to E3.20 (see Table CDAT 4.11 below). The repeated identical questions are not either subsidiary or feedback questions since it does not extend the dialogue or help students to think more.

**Dialogue 4.11 Teacher Eva 2007-03-02P4 w/ CCT**

T1: whatever one would represent shaking your hand faster; move your hand back and forth faster. *Q3*

T1: David might be right, he might be wrong.  
SS: He’s definitely wrong.  
R3.2 There I am.  
R3.3 It’s not working.  
R3.4 Where am I? Hey, green X, where are you going?  
R3.5 Get off my spot.  
R3.6 This is me going back and forth.  
R3.7 You, get away.  
R3.8 Where are you?  
R3.9 Get off me.  
R3.10 I’m frozen.  
R3.11 This one, moving up and down.  

T: Find your way to that graph;  
P3.12 I don’t care which one;  
P3.13 which ever one represents shaking your hand faster.  

SS: Wait, wait.  
R3.14  
T: You’ve got about five seconds.  
R3.15  
S: Get away from my spot, green X.  
R3.16  
T: This one? It would be right no matter which one you’re on,  
P3.17 because it’s on both graphs, so go ahead and move it.  
P3.18 Go ahead and move it; go ahead and make a decisive decision and decide what one.  

SS: [inaudible]  
R3.18  
T: Ok, which one represents moving your hand faster?  
R3.19  
SS: The green one.  
R3.20  
T: What does that represent? More faster, more higher?  
R3.21  
S: Higher frequency.  
R3.22  
T: Higher frequency.  
P3.23 The faster you shake your hand back and forth, the higher the frequency.  

---

**Table CDAT 4.1** Teacher Eva 2007-03-02P4 w/ CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Type</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ss' Explanation (NE)</td>
<td>Ss' Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific knowledge (SK)</td>
</tr>
<tr>
<td>Explanation/Examples</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.20</td>
</tr>
<tr>
<td>Question/Prompt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Student Response/Question**

| Feedback |       | q3.19 |
| L3:Elaborative |               |       |
| L2:Corrective |                | 3.19 | 3.15,3.16, |
| L1:Evaluative |                | 3.1  |       |

The effect on classroom discourse of implementing CCT depends highly on the teachers. In the Dialogues 4.11 and 4.12, the teacher just collected students’ responses by using the connected classroom technology (CCT) providing some fun for the students,
but she does not provide much feedback about the students’ responses or feedback questions. In that dialogue 4.12, after teacher Eva and her student teacher collected all students’ answers, they just provide explanations without many interactions with the students as shown in Table CDAT 4.12.

Dialogue 4.12 Teacher Eva 2007-03-02 P4 w/ CCT

T: These are two of your waves. Assume that one of you sent this wave with this amplitude for one side, and the other one said this wave. So then when these two waves meet, you’re going to use your point to show where the amplitude of that new one would be. So when they met in the middle, where do you think that one would be – the center point? So where along here do you think the waves will meet?

S: Good question.

T: If one person sends the wave this way, this pink one, and the other person sends the wave this way in the slinky, when they go to the center, where is the amplitude going to be? You have the pink one that’s here and you have the green one that’s here. So where along here do you think the amplitude is going to be?

T1: What kind of interference do you think it will be? Constructive or destructive?

SS: Constructive.

T1: So that would tell you something about where you might be.

T: So pick a point along this line. You should only have? What do you think we’re doing? So would this be constructive interference or destructive interference?

SS: Hum. Yeah, smarty.

T: Go ahead and find the point where you think the amplitude is going to be. Stop making smiley faces and put your point where you think it should be. Hey, Robert… We had fun.

SS: [inaudible]. Hey, Robert… We had fun.

T: It should be somewhere on this line.

S: Hey, Robert.

T: Allright, so find out where the amplitude should be. All you need to do is add these two together, and you may have noticed that all I’m doing is making
sine functions to make the waves. *E4.16* So I just add these together and I should get where they should meet. *E4.17* So this is where the amplitude should be. *E4.18* You add the two waves together. *E4.19* So if I take this box; what’s this box? I have two boxes, that gives me an amplitude of two. *E4.20* The same here; *E4.21*

Table CDAT 4.12 Teacher Eva 2007-03-02P4 w/ CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Type</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge Type</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ss’ Explanation (NE)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific Knowledge (SK)</td>
<td></td>
</tr>
<tr>
<td>Explanation/Examples</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4,4,1,4,2,6,4.6</td>
</tr>
<tr>
<td>Question/Prompt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.3,4,4.4,7,4.8,4.9,4.10,4.12</td>
</tr>
<tr>
<td>Student Response/Question</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.11,4.12,4.13,4.14</td>
</tr>
<tr>
<td>Feedback</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>cR4, 4.9</td>
</tr>
</tbody>
</table>

Table 4.10 below shows teacher Eva’s utterances of explanations, questions, feedback, and ratio of level 2 and level 3 feedback vs. questions counted in her analyzed classes. In all the episodes, the numbers of all the teacher’s utterances are relatively small as well as the number of dialogues. In her review discourse episodes with PS, after questioning each problem, she waited and cast the same questions and prompts.

Table 4.10 Teacher Eva’s Questions and L3 Feedback

<table>
<thead>
<tr>
<th>Class</th>
<th>Episode Type</th>
<th>Episode Time (m:s)</th>
<th># of Dialogues</th>
<th># of Explanations</th>
<th># of Questions</th>
<th># of L2 Feedback</th>
<th># of L3 Feedback</th>
<th>L2&amp;L3 /Qs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Review after PS*</td>
<td>3:45</td>
<td>5</td>
<td>12</td>
<td>8</td>
<td>18</td>
<td>1</td>
<td>2.38</td>
</tr>
<tr>
<td>2</td>
<td>Review after PS*</td>
<td>5:26</td>
<td>4</td>
<td>15</td>
<td>10</td>
<td>16</td>
<td>0</td>
<td>1.60</td>
</tr>
<tr>
<td>3</td>
<td>Review after a lab</td>
<td>15:18</td>
<td>8</td>
<td>15</td>
<td>19</td>
<td>16</td>
<td>0</td>
<td>0.84</td>
</tr>
<tr>
<td>4</td>
<td>Review after a lab</td>
<td>19:09</td>
<td>8</td>
<td>20</td>
<td>26</td>
<td>8</td>
<td>2</td>
<td>0.38</td>
</tr>
<tr>
<td>5</td>
<td>Review after a lab</td>
<td>13:51</td>
<td>6</td>
<td>20</td>
<td>21</td>
<td>15</td>
<td>2</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1:08:48</td>
<td>31</td>
<td>82</td>
<td>84</td>
<td>73</td>
<td>5</td>
<td>0.93</td>
</tr>
</tbody>
</table>
**Length of Dialogue (LOD)**

Teacher Eva’s dialogues have mostly 3 to 6 LODs (68%) since she used just one confirmation, a feedback, or a subsidiary question and then ends up with L2 feedback in each dialogue (see Figure 4.13 below). Her unique dialogue pattern increases the average LOD but she rarely extends her dialogues more than 7 LODs. Since she often used level 2 feedback even for the feedback questions, the dialogue patterns in her episodes were not extended more than two cycles of the QRE pattern.

![Figure 4.13 Teacher Eva’s LOD](image)

**Levels of Feedback**

As shown in Figure 4.14 below, teacher Eva mostly used level 2 corrective feedback. Level 2, corrective feedback, usually terminates the dialogue with confirmative
information and when it is used as a feedback question, it extends by one the LOD with another corrective feedback.

Dialogue 4.13 Teacher Eva 2007-03-02P4 w/ CCT

T1: So what kind of interference would this be if they’re both in the same direction; if both waves are in the same direction? Q6.8 What kind of interference would that be? Q6.9

S: Positive. R6.9

T1: Constructive or destructive? fQ6.10

SS: Constructive. R6.10

T1: It would be constructive. F6.10

Table CDAT 4.13 Teacher Eva 2007-03-02P4 w/ CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Ss’ Explanation (NE)</td>
<td>Ss’ Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific Knowledge (SK)</td>
</tr>
<tr>
<td>Explanation/Examples</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Question/Prompt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student Response/Question</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>L3:Elaborative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L2:Corrective</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L1:Evaluative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the Dialogue 4.13 above, the feedback question 6.10 is a L2 feedback since it provides corrective information as a form of question and another L2 feedback F6.10 follows with the same corrective information. Therefore, its LOD is 4 and a large portion of her dialogues have the same patterns as shown in Table CDAT 4.13.
Students’ Utterances vs. Teachers’ Utterances

All of teacher Eva’s classroom discourse happened with CCT as a review of problem solving and the students talked about their cursors on the screen and had fun with others. For this reason, N/A utterances occupied up to 50% of the classroom discourse time as shown in Figure 4.15 below.
Overall Comparison and Assertions for RQ1

Components of Classroom Instructions

In this study, class components are reframed for the analysis with CDAT. A class consists of: classroom activities and classroom talk, and on the other hand, classroom talk consists of classroom discourse and other talk, while classroom discourse includes several classroom episodes that consists of several dialogues and a dialogue consists of students’ and a teacher’s utterances (see Table 4.11).

Table 4.11 Components of a Class

<table>
<thead>
<tr>
<th>Classroom Activities</th>
<th>Whole Classroom Talk (Between a teacher and students)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Off Topic Talk</td>
</tr>
<tr>
<td></td>
<td>Classroom Discourse on Topic</td>
</tr>
<tr>
<td>Lab, Problem Solving, Group Work, Discussion, Demonstration, ...</td>
<td>Episode 1</td>
</tr>
<tr>
<td></td>
<td>Managing or disciplining students’ behaviors</td>
</tr>
<tr>
<td></td>
<td>Explaining about activities, grades, test, or etc.</td>
</tr>
<tr>
<td></td>
<td>Episode 2</td>
</tr>
<tr>
<td></td>
<td>Dialogue 1</td>
</tr>
<tr>
<td></td>
<td>Dialogue 2</td>
</tr>
<tr>
<td></td>
<td>Teacher’s Utterances and Students’ Utterances</td>
</tr>
<tr>
<td></td>
<td>.....</td>
</tr>
</tbody>
</table>

Table 4.12 below shows what components of the classes are used for the analysis in this study. Although the total class time varies, the time of classroom talk time and discourse time are similar to each other compared to their class time. However, this table provides some notable information about the teachers’ use of their class time.
### Table 4.12 Observed Classroom Discourse and Classroom Utterances

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Total Class Time (h:m:s)</th>
<th>All Classroom Talk* (h:m:s)</th>
<th>Discourse Time (h:m:s)</th>
<th># of Episodes</th>
<th># of Dialogues</th>
<th># of T’s Utterances</th>
<th># of Ss’ Utterances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ann</td>
<td>3:36:26</td>
<td>1:29:11</td>
<td>0:39:54</td>
<td>9</td>
<td>59</td>
<td>382</td>
<td>150</td>
</tr>
<tr>
<td>Ben</td>
<td>7:01:37</td>
<td>2:16:41</td>
<td>1:03:28</td>
<td>6</td>
<td>109</td>
<td>373</td>
<td>158</td>
</tr>
<tr>
<td>Cory</td>
<td>3:03:09</td>
<td>1:47:43</td>
<td>1:08:48</td>
<td>9</td>
<td>91</td>
<td>558</td>
<td>263</td>
</tr>
<tr>
<td>Daisy</td>
<td>3:34:52</td>
<td>1:47:05</td>
<td>1:09:16</td>
<td>10</td>
<td>104</td>
<td>634</td>
<td>271</td>
</tr>
<tr>
<td>Eva</td>
<td>4:17:56</td>
<td>1:30:39</td>
<td>0:57:30</td>
<td>5</td>
<td>31</td>
<td>244</td>
<td>88</td>
</tr>
<tr>
<td>total</td>
<td>21:34:00</td>
<td>8:51:56</td>
<td>4:58:56</td>
<td>39</td>
<td>394</td>
<td>2191</td>
<td>930</td>
</tr>
</tbody>
</table>

*Exclude student-student talk

Although teacher Ben has relatively much more class time analyzed in this study, he has relatively small amount of discourse time. He also has a large number of dialogues but has relatively small number of teacher’s and students’ utterances. Teacher Cory has a large amount of discourse time compared to total class time and has relatively many teacher’s and students’ utterances. Teacher Eva has a small number of dialogues compared to her class time and the numbers of other teachers’ dialogues.

### Descriptive Statistics of Teacher Feedback

Although the number of questions and feedback does not tell everything about the classroom discourse, it can show how much the teachers use each level of feedback in their classrooms. Except teacher Ben, all the teachers almost never use level 1 evaluative feedback as shown in Table 4.13 below. The reason why teacher Ben had considerable level 1 feedback is that he often repeated students’ responses without any follow up information. Furthermore, when he collected students’ responses by CCT, he asked his students to vote for the best answer by raising their hands. On the other hand, teacher
Cory provides a large portion of level 3 feedback and the ratio of L2 and L3 feedback to teacher’s questions (Qs) is much greater than 1 as shown in Table 4.13 below since she listened to students’ answers from one student to the next and gave feedback.

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Total # of Feedback</th>
<th># of Questions</th>
<th>% of L1</th>
<th>% of L2</th>
<th>% of L3</th>
<th>L2&amp;3F /Qs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daisy</td>
<td>201</td>
<td>240</td>
<td>0</td>
<td>11.9</td>
<td>88.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Cory</td>
<td>193</td>
<td>127</td>
<td>0</td>
<td>35.8</td>
<td>64.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Ann</td>
<td>128</td>
<td>159</td>
<td>3.9</td>
<td>18.0</td>
<td>77.3</td>
<td>0.8</td>
</tr>
<tr>
<td>Ben</td>
<td>128</td>
<td>95</td>
<td>50.1</td>
<td>3.9</td>
<td>43.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Eva</td>
<td>77</td>
<td>84</td>
<td>0</td>
<td>6.5</td>
<td>93.5</td>
<td>0.9</td>
</tr>
<tr>
<td>total</td>
<td>727</td>
<td>705</td>
<td>9.6</td>
<td>17.3</td>
<td>72.6</td>
<td>0.9</td>
</tr>
</tbody>
</table>

How can this information be interpreted? Through the analyses with CDAT, I have developed a model and terms that can help in interpreting and making some suggestions for improving science classroom discourse. The model that will be presented in the next section is connected to the research question number 1; a combined model that incorporates aspects of research question 2 will be presented at the end of this chapter.

The major findings from the analysis for RQ1 are length of dialogue (LOD), use of subsidiary or feedback questions, levels of feedback, and ratios of teachers’ and students’ utterances. The results of comparisons of these aspects will be presented in order after presenting the LOD model.
**LOD Model of Discursive Dialogue**

Classroom discourse usually deals with questions and consists of several dialogues between a teacher and students. Each dialogue deals with a specific question or topic that serves as a signal for starting a new dialogue. I named this type of dialogue *discursive dialogue* since one of the definitions of “discursive” is “proceeding coherently from topic to topic” or “proceeding to a conclusion through reason rather than intuition.” Classroom discursive dialogue is not an argumentation or explanation since its purposes are not to persuade students or explain something. Although discursive dialogue has the aspects of argumentation and explanation, its fundamental purpose is to help students to reach a certain point of understanding or learning.

Figure 4.16 is a LOD model that explains how classroom discursive dialogue supports students’ moving forward to the moment of understanding. A discursive dialogue starts with a new question by a teacher. Teachers often utilize several subsidiary questions to help the students figure out what the questions are or what the process of understanding is. However, the levels of subsidiary questions and the delivering methods are flexible and highly dependent on the students’ understanding level.

After receiving first one or several students’ answers, the length of dialogue (LOD) is usually determined by the teacher’s first feedback or subsidiary question. If it is a level 1 evaluative feedback such as praising, giving grades or comparing with others, there are usually no more answers from students related to the questions and answers. Therefore, it usually terminates the dialogue. If teacher’s response is a level 2 corrective feedback, telling if the students’ answers are right or wrong, the dialogue also sometimes
ends after it without any more students’ responses. However, in many cases a level 2 feedback is a confirmative question or a directive hint which extends the dialogue with follow-up feedback questions. While, when teacher’s response is a level 3 elaborative feedback that is providing direction or opportunity to think more with specific information, it usually extends the dialogue with another turn of students’ responses.

A teacher often casts subsidiary questions regardless of the students’ responses to lead the students to the intended directions, which also extends the length of dialogue. However, when a subsidiary question is also a response to the students’ previous answer, it can be considered as a level 3 feedback as well as a feedback question, which more often extends the LOD. Both a subsidiary question and a level 3 feedback including feedback question have a critical role to extend the LOD, and increase the number of turn-changes in the discourse.

In the model in Figure 4.16 below, the dotted circles indicate the levels of students’ understanding for the topic/question which can be measured by students’ responses including students’ questions. Not every long discursive dialogue is productive. However, a longer dialogue can help students learn how to make connections between reasoning components and their ideas through the repeated questioning and answering (Hicks, 1996). Overall, this model shows what a subsidiary and level 3 feedback’s role is in a dialogue and how LODs are related to supporting students’ understanding through the dialogue.
Overall LOD Comparisons

All the teachers’ total classroom discourse time is about 70 minutes each except teacher Ann’s which is only about 40 minutes. The figure 4.17 below shows evident differences in frequency of level of LODs. Teacher Ben’s classroom dialogues’ LODs are mostly 1 and 2 while teacher Cory’s are mostly larger than 3. Except teacher Ben, all the
teachers extend their discursive dialogues more than 3 LODs that indicates their dialogues are beyond simple QRE patterns and they often use subsidiary or feedback questions.

Figure 4.17 Number of Dialogues by LODs

We cannot tell which classroom discourse is better or worse by examining the numbers of higher LODs. However, descriptions about their classroom dialogues can be drawn from the information about LODs. The higher LOD dialogues in the classroom, the more interactions occur between a teacher and students and we can expect that the more students’ understanding/learning happens. Table 4.14 shows the Spearman’s correlations between each teachers’ or students’ utterance, feedback, and LOD. Unquestionably if teachers ask more questions, then students will answer more and the length of dialogues will increase. However, the more questions could mean the more simple QRE patterns of dialogues not the higher LODs. Therefore, if the majority of
classroom dialogues have less than 2 LODs, it means they are just simple QRE patterns without many subsidiary or feedback questions. The results in Table 4.14 show the relationships between LOD and teachers’ utterance types and students’ utterances which show simply more questions and feedback increase LODs. Therefore, to lengthen LODs in classroom dialogues with more students’ responses, teachers need to utilize more questions and feedback but they must be more subsidiary and feedback questions.

Table 4.14 Correlations between Each Number of Utterance, Feedback, and LOD

<table>
<thead>
<tr>
<th></th>
<th>T’s Utt*</th>
<th>Ss’ Utt</th>
<th>T’s Ex*</th>
<th>T’s Qs*</th>
<th>L1 Feed</th>
<th>L2 Feed</th>
<th>L3 Feed</th>
<th>LOD*</th>
</tr>
</thead>
<tbody>
<tr>
<td>T’s Utt</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ss’ Utt</td>
<td>.582**</td>
<td>1</td>
<td></td>
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<tr>
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<td>.750**</td>
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<td></td>
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</tr>
<tr>
<td>T’s Qs</td>
<td>.614**</td>
<td>.567**</td>
<td>.254**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1 Feed</td>
<td>-.304**</td>
<td>-.261**</td>
<td>-.327**</td>
<td>-.240**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L2 Feed</td>
<td>.616**</td>
<td>.662**</td>
<td>.229**</td>
<td>.489**</td>
<td>-.394**</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L3 Feed</td>
<td>.309**</td>
<td>.447**</td>
<td>.092</td>
<td>.098</td>
<td>-.201**</td>
<td>.241**</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>LOD</td>
<td>.650**</td>
<td>.884**</td>
<td>.229**</td>
<td>.603**</td>
<td>-.162</td>
<td>.708**</td>
<td>.485**</td>
<td>1</td>
</tr>
</tbody>
</table>

* Utt: Utterances, Ex: Explanations, Qs: Questions, LOD: Length of Dialogue
** p < .01, N = 394 (number of dialogues)

Table 4.15 below shows each utterance’s mean and standard deviation (SD) per dialogue. Teachers usually have more opportunity to talk in a classroom discursive dialogue. More teachers’ talk does not represent a better or worse classroom discourse. However, the role of teachers or teachers’ talk should be extending students’ thought and providing more opportunities to talk. The results in this study show that teachers can extend the LODs and receive more students’ responses by utilizing more subsidiary questions and feedback questions. A level 3 feedback does not have to be sophisticated or
technical. In this study, most of the level 3 feedback are questioning students’ thinking with phrases such as “what is the reason?”, “why do you think like that?”, or “explain more?” However, those questions infrequently happened in the classrooms analyzed in this study.

Table 4.15 Mean and SD of number of Utterances in a Dialogue

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>T’s Utterances</td>
<td>5.56</td>
<td>4.13</td>
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<tr>
<td>Ss’ Utterances</td>
<td>2.36</td>
<td>1.85</td>
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<tr>
<td>T’s Explanations</td>
<td>1.75</td>
<td>2.81</td>
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<tr>
<td>T’s Questions</td>
<td>1.98</td>
<td>1.81</td>
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<tr>
<td>L1 Feedback</td>
<td>.18</td>
<td>.46</td>
</tr>
<tr>
<td>L2 Feedback</td>
<td>1.34</td>
<td>1.30</td>
</tr>
<tr>
<td>L3 Feedback</td>
<td>.32</td>
<td>.73</td>
</tr>
<tr>
<td>LOD</td>
<td>3.68</td>
<td>2.83</td>
</tr>
</tbody>
</table>

* N = 394 dialogues

When teachers’ feedback is combined with subsidiary questions, the dialogues are more extended and receive more students’ responses as shown in the cases of teachers Cory and Ann. However, using subsidiary questions is not an easy task for teachers since they must have strong content knowledge, pedagogical content knowledge (PCK), and students’ understanding levels as reported by many studies (Hackling et al., 2010; Hewson & Hewson, 2003; Hicks, 1996; Lemke, 1998; Sanders et al., 1993).

**Subsidiary Questions and Feedback Questions**

The number of subsidiary or feedback questions used can be indicators of LOD. Figure 4.18 shows how much the teachers use subsidiary questions and L3 feedback. Although the class time and classroom discourse times are all different, the amount of
their time does not match with the number of dialogues, questions, or feedback. Teacher Ben has the longest class time but the classroom discourse time is almost the same as teacher Cory, Daisy, and Eva. One specific difference in Figure 4.18 is that teacher Cory uses more feedback questions than subsidiary ones.

Figure 4.18 Teachers’ Use of L3 Feedback and Sub-Questions

Figure 4.19 below shows possible relationships between the number of higher LODs and the number of sub-questions and L3 feedback. When comparing the numbers of higher LODs (> 3 or > 7) in Figure 4.19, they increase as the L3 and sub-questions increase except for teacher Cory since she has unexpectedly higher levels of lengthy discursive dialogues (LOD > 3 and LOD > 7). The reason might be that teacher Cory has more L3 feedback than sub-questions (see Figure 4.18) that could increase the number of higher LOD dialogues.
Using subsidiary questions even as feedback questions strongly depends on teachers’ content knowledge, PCK, and more importantly teachers’ experiences in using those questions. For example, although teacher Ben has a Ph.D. degree in physics, his classroom discourse cannot be considered as productive as teacher Cory’s who holds an undergraduate major not in science. What are the differences or what makes the differences? In the next section on RQ2, I investigated how the classroom discourse is different with regards to the aspects of scientific inquiry and reasoning.

Figure 4.19 L3 Feedback and Sub Questions VS. Higher LODs
**RQ 2. How does teachers’ feedback support scientific classroom discourse?**

The results for the RQ2 will be presented in order of (1) use of Reasoning Components (RC), (2) Number of Reasoning Components (#RC) in a dialogue, (3) Movements in Reasoning Components (MRC) between dialogues, (4) #RC and MRC with teachers’ Feedback/Questions/Explanations. Although, in this study, CDAT includes the scientific reasoning components of theories/model (TD) and students’ (naïve) reasoning (NR), no instances of these coding categories occured. Therefore, how much the teachers used the other five components of students’ experiences (EX), students’ naïve knowledge (NK), scientific knowledge (SK), observations and data (OD), and patterns from data (PD) will be presented.

**Teacher Ann**

**Use of Scientific Reasoning Components**

Although teacher Ann used SK the most, she uses a good amount of EX, OD, and PD depending on the class type and content. In the classes 1 and 2, she tried to connect scientific concepts to students’ experiences. In most classes, she uses more than 3 reasoning components by making connections to each other components (see Table 4.17).
In the Dialogue 4.14 below, teacher Ann tried to make a connection to students’ everyday experiences with the concept of speed. At first the teacher asked about the concept of speed directly and then with some reason, she asked about the students’ everyday experiences regarding the concept of speed (Q1.1).


T: So what is speed? Q1 You all should probably be able to tell me that without even having to look at your book because you speed to school every day, right? Q1.1

SS: Nope. No. R1.1

T: You don’t? Don’t you all ride the school bus? Q1.2

SS: Yes. No. R1.2

T: Is speed involved in getting to school? Q1.3

S: Yeah. R1.3

T: Yeah, what is speed? Q1.4

SS: Movement. R1.4

T: It’s movement, ok, F1.4 and what two things do we use to calculate speed? Q1.5
SS: Distance traveling over time. *R1.5*
T: Distance traveled over... *fQ1.6*
SS: Time. *R1.6*
T: Time. *F1.6*

Table CDAT 4.14  Teacher Ann 2007-04-26P1 4.14 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
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<tbody>
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<td></td>
<td>Ss’ Explanation (NE)</td>
<td>Ss’ Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific knowledge (SK)</td>
<td>Observation/ Data (OD)</td>
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<tr>
<td>Explanation/Examples</td>
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<td></td>
</tr>
<tr>
<td>Question/Prompt</td>
<td>1.1,1.2,1.3</td>
<td></td>
<td>1.1,4,1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student Response/Question</td>
<td>1.1,1.2,1.3</td>
<td></td>
<td>1.4,1.5,1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>L3:Elaborative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L2:Corrective</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>L1:Evaluation</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

In the Dialogue 4.14 above, through the utterances Q1 to R1.4, the students engaged in the conversation little by little with a more visual concept of speed (R1.4).

When the students had a concept or experiences in their mind, the teacher asked a linked subsidiary question (Q1.5) and it drew another student’s answer extending the dialogue even longer.

**Number of Reasoning Components (#RC) in a Dialogue**

In the Dialogue 4.15 below, teacher Ann first asked about scientific concepts (SK) and then she cast three different subsidiary questions about how to calculate average speed (Q7.1 to Q7.3). She provided an example of how speed changes in everyday life, starting from E7.6 and E7.7 coded as EX and made an observation from it, E7.8 that is “not going to be the same speed all the time” coded as OD. Therefore, her discourse movement on reasoning components in this dialogue is SK, EX, and OD and the number of reasoning components (#RC) is three as shown in Table CDAT 4.15.
Dialogue 4.15 Teacher Ann 2007-04-26P3 w/o CCT

T: So what is your average speed? \textit{Q7} Speed itself is distance over time, but what is your average speed? \textit{Q7.1} If you had to take an average, what does that mean? \textit{Q7.2} We’ve been doing math [inaudible], math practice. \textit{Q7.3}

S: You add and divide. \textit{R7.3}

T: One person – raise your hand. One person. Ron? \textit{P7.4}

S: Go half the speed you regularly go? \textit{R7.4}

T: You go half the speed your regularly go? If I’m averaging speeds? \textit{fQ7.5}

S: Like if [inaudible]. \textit{R7.5}

T: Let me put it this way, I’ve been starting to bike. \textit{E7.6} I ride my bike; I’m training for the MS 150, so if I get on my bike and I ride around White Rock Lake, \textit{E7.7} I’m not always going to be going the same speed at all times. \textit{E7.8}

SS: No. \textit{R7.8}

T: Same thing in your car; are you always going to be going the same speed all the way to your destination? \textit{Q7.9}

SS: No. \textit{R7.9}

T: No. Why? What’s happening between? \textit{fQ7.10}

S: The speed limit goes faster or slower. \textit{R7.10}

T: Yeah, the speed limit may change. \textit{F7.10} You may have to slow down for a school zone, or what else? \textit{Q7.11}

S: You have to get to the highway. \textit{R7.11}

Table CDAT 4.15 Teacher Ann 2007-04-26P3 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
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<th>Scientific Reasoning (SR)</th>
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<td>7.8</td>
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<td>Question/Prompt</td>
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<td>7.9,7.11</td>
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<td>Student Response/Question</td>
<td>7.3,7.4,7.5</td>
<td>7.8,7.9,7.10,7.11</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>1.3:Elaborative</td>
<td>q.7.10</td>
<td></td>
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<tr>
<td></td>
<td>1.2:Corrective</td>
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<tr>
<td></td>
<td>1.1:Evaluative</td>
<td>\textit{q7.5}</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Figure 4.20 show the frequency of reasoning components (RCs) in dialogues used in teacher Ann’s classroom discourse. Although, she used a single component in many dialogues (63%), she also has a relatively good amount of dialogues that have two or
three components in a dialogue (29%). Reasoning movement in her dialogues are also variable and include SK to OD, SK to EX to OD, or OD to PD. These movements in a dialogue do not tell everything about scientific discourse but it shows, at least, how teacher Ann tries to make connections among the components of scientific reasoning. Although how to include high levels of thinking such as induction, deduction, or inference strongly depends on teachers’ capacities, still the number of reasoning components the teachers used could serve as a gauge about their ability to lead the classroom discourse to be scientific.

![Teacher Ann's RC](image)

**Figure 4.20 Number of RC used in teacher Ann’s Dialogues**

Another aspect about the teachers’ use of RC is the movement between the dialogues. When the teacher moves on to a new dialogue with a new question or topic,
the teacher can also purposely use different reasoning components from the ones used previously.

**Movement in Reasoning Components (MRC) between Dialogues**

Teacher Ann has 59 dialogues in her classroom discourse observed and analyzed and she also showed various movements in reasoning components when she moves on to a new dialogue. In the Dialogue 4.16 below, three dialogues show some movement in reasoning components. The first dialogue from P1.5 to F1.17 is about observation/data (OD) where teacher Ann asked about specific descriptions about the data that students collected from the previous lab activity such as directions, time, and distances. Then, she started the second dialogue from Q2 that is a new question requesting a different answer from the previous dialogue. The second dialogue is about what velocity is, which belongs to the reasoning component of scientific knowledge (SK) since it is about a definition or concept. Thus, the movement in reasoning components between the first dialogue and the second is from OD to SK (see Table CDAT 4.16).

**Dialogue 4.16 Teacher Ann 2007-04-26P3 w/o CCT**

T: Hold on. You’ve got to tell me where he had to start; **P1.5 you’ve got to be specific in your description. P1.6** You have to start how far away from the wall? **Q1.7**  
S: One? **R1.7**  
T: He had to start one foot away **F1.7** and then which way did he have to walk? **Q1.8**  
SS: Backwards. **R1.8**  
T: He had to go back. **F1.8** How many meters back did he have to go? **Q1.9**  
SS: Three. **R1.9**  
T: One. **F1.9** See how that ended up one extra meter? **Q1.10**  
S: Yeah. **R1.10**  
T: How long did he have to walk back to that other meter? **Q1.11**  
S: Three. **R1.11**
T: How long did it [inaudible]? Q1.12
S: Three. R1.12
T: Ok, F1.12 so he had to walk back for how many seconds? Count. How many seconds? How many seconds did he have to walk backwards for? Q1.13
SS: Three. R1.13
T: Three, right? F1.13 So he had to judge it. How did we get that straight line? Q1.14
S: Just stay there. R1.14
T: He stopped, right? F1.14 And what was our speed at that point? Q1.15
SS: Zero. R1.15
T: Zero; you weren’t moving, were you? F1.15 Then, what did we do here? How long did he have to stand there and do nothing? Q1.16
S: Like four seconds. R1.16
T: Yeah, about one, two, three, four seconds, F1.16 and after four seconds what did he have to do? Q1.17
S: Walk back. R1.17
T: Walk forward again, right? Ok. F1.17 now at that point, at what two points did the velocity change on this? Remember what – for velocity to change are what two things? Q2
S: Velocity. R2
T: What two things make up velocity? Q2.1
S: Speed. R2.1
T: Speed or…fQ2.2
S: Direction. R2.2
T: Direction. F2.2 So can you tell me the two places on this graph where he changed velocity? Q3
S: In the middle. R3
T: One – we’re almost done – two…fQ3.1
S: Where it changed? qR3.1
T: Show me where he changed velocity. Show me. P3.2

Table CDAT 4.16 Teacher Ann 2007-04-26P3 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
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<tbody>
<tr>
<td>Explanation/Examples</td>
<td>S's Explanation</td>
<td>S's Experience</td>
<td>Naive Knowledge</td>
<td>Scientific knowledge</td>
<td>Observation Data</td>
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<td>Question/Prompt</td>
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<td></td>
<td>2.1</td>
</tr>
<tr>
<td>Student Response/Question</td>
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<td></td>
<td></td>
<td></td>
<td>2.2,1.2.2</td>
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<tr>
<td>Feedback</td>
<td>1.3:Elaborative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2:Corrective</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>1.1:Evaluative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

154
In the Dialogue 4.16, the third dialogue started with the question Q3 that she asked about the places where velocity changed on the graph. This question is not about observation or data but about a pattern that requires a high level of thinking such as induction, deduction, or inference with the observation/data they collected. Therefore, the reasoning component used in the number 3 dialogue belongs to PD. In this example, she also showed a movement in reasoning components within a dialogue when she asked Q1.14, a subsidiary question of the question number 1 because the first question is about the description of an object’s movement. Although Q1.14 is about speed, it is connected to the previous answer “stopped” which is not from inference but from observation so it belongs to OD in the table. Teacher Ann shows 27 movements that go to a different reasoning component out of 58, which is .46 possibility of change, when a new dialogue starts. I named the possibility Movements in Reasoning Components between dialogues (MRC).

#RC and MRC with teachers’ Feedback/Questions/Explanations

Table 4.18 shows the Spearman’s correlations between each reasoning component and the number of reasoning components (#RC) in a dialogue, movements in reasoning components (MRC) between dialogues, teachers’ questions/explanations/feedback, and LOD. #RC has significant correlations with all the reasoning components and all the teacher’s utterances except SK while MRC only has significant relationships with PD and teacher’s explanation utterances, which means teacher Ann changes her utterances of
reasoning components mostly when she deals with PD with explanations not with questions or feedback.

Table 4.17 Correlations between RCs, #RC, MRC, LOD, and teacher Ann’s Utterances

<table>
<thead>
<tr>
<th></th>
<th>#RC</th>
<th>MRC</th>
<th>EX</th>
<th>SK</th>
<th>OD</th>
<th>PD</th>
<th>T’s Qs</th>
<th>T’s Ex</th>
<th>L2 Feed</th>
<th>L3 Feed</th>
<th>LOD</th>
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<tbody>
<tr>
<td>#RC</td>
<td>1</td>
<td>.419**</td>
<td>.480**</td>
<td>.215</td>
<td>.566**</td>
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<td>.604**</td>
<td>.307**</td>
<td>.470**</td>
<td>.559**</td>
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<tr>
<td>MRC</td>
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<td>-.157</td>
<td>.215</td>
<td>.518**</td>
<td>.232</td>
<td>.339**</td>
<td>-.085</td>
<td>.222</td>
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</tr>
<tr>
<td>LOD</td>
<td>.535**</td>
<td>.191</td>
<td>.206</td>
<td>.460*</td>
<td>.291*</td>
<td>.319**</td>
<td>.743**</td>
<td>.318*</td>
<td>.648**</td>
<td>.435**</td>
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</tbody>
</table>

* #RC: Number of Reasoning Components in a dialogue, MRC: Movements in Reasoning Components between dialogues
** p < .01

The length of dialogue (LOD) has a significant correlation with #RC but not with MRC. This seems to be reasonable since MRC is about movements between dialogues not about how many RCs used within a dialogue.

**Teacher Ben**

Use of Scientific Reasoning Components

Teacher Ben mostly used the SK reasoning component regardless of the class type. The use of his RCs is very limited in that he mostly asked about scientific concepts and definitions in almost all his classroom dialogues as shown in Table 4.19. Although he had a lab section in his classes 2 and 3 when he explained the principles of electric motors, he did not make any connections with the experiment or rather he used many equations, definitions, and scientific concepts.
<table>
<thead>
<tr>
<th>Class</th>
<th>Episode Type</th>
<th>Content</th>
<th>EX*</th>
<th>SK*</th>
<th>OD*</th>
<th>PD*</th>
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<td>1</td>
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<td>Electric Current, Electric Energy</td>
<td>6</td>
<td>148</td>
<td>20</td>
<td>0</td>
<td>3</td>
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<td></td>
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<td>2</td>
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<td>Electric Power, Motor</td>
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<td>20</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Lecture before a Lab</td>
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<td>4</td>
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<td>1</td>
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<td>Speed vs. Frequency</td>
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<td>9</td>
<td>392</td>
<td>35</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

* EX: Students’ Experiences, SK: Scientific Knowledge, OD: Observation and Data, PD: Patterns from Data

Teacher Ben’s typical dialogue pattern is clearly simple QRE focusing on SK. In the Dialogue 4.17 below, teacher Ben continually asked about concepts and definitions coded as SK in CDAT. In this review class after problem solving seatwork, he only asked about SK repeating exactly the same questions like Q3.2 and Q3.3, which are not even subsidiary questions. In the second dialogue in this example, teacher Ben asked about the symbol for current, Q3, first but the next question Q3.1 is about the unit for current, which is not relevant with Q3 and even Q3.2 but with the question Q4.

Dialogue 4.17 Teacher Ben 2007-04-12P1 w/o CCT

**T:** Let us go to Number 20. *P2* What type of circuit could give you more current flowing than two light bulbs and a source? *Q2.1* A series or parallel? Ed. *Q2.2*

**S:** Parallel. *R2.2*

**T:** Parallel. Very good! *F2.2* Fourteen. What is the symbol for current? *Q3* What is the unit for current? *Q3.1* What is the symbol? For current? *Q3.2* What is the symbol? What letter do we use to represent current? *Q3.3*

**S:** [inaudible]? *R3.3*
T: Okay. That is a schematic symbol. *F3.3* What symbol do we use in the equation? *Q3.4*

S: Yes. 5. I know science. Oh my gosh! *R3.4*

T: What are the units? *Q4*

S: Well, I do. *R4*

S: Amps? *R4.1*

T: Amps. *F4.1*

---

**Table CDAT 4.17 Teacher Ben 2007-04-12P1 w/o CCT**

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Sc' Explanation (NE)</td>
<td>Sc' Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific Knowledge (SK)</td>
<td>Observation/Data (OD)</td>
</tr>
<tr>
<td>Explanation/Examples</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.1,2.2,3.3</td>
</tr>
<tr>
<td>Question/Prompt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.3,2.3.4.4</td>
</tr>
<tr>
<td>Student Response/Question</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.4,4</td>
</tr>
<tr>
<td>Feedback</td>
<td>I.3: Elaborative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>I.2: Corrective</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>I.1: Evaluative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Dialogue 4.17 above occurred in a review episode and the Dialogue 4.18 below happened in a lecture section. In the both dialogues, teacher Ben only used SK reasoning component. In the Dialogue 4.18 below, teacher Ben spent a certain amount of the class time explaining the concept of electric energy almost without any interaction with students. Even in other types of classes, he almost always used only one reasoning component of SK.

**Dialogue 4.18 Teacher Ben 2007-04-12P1 w/o CCT**

T: Alright, first equation is Electrical Energy= (# Watts) x (# Seconds). *E2* Everybody should have this equation on your paper. *E2.1* Put it at the top wherever you have room. *E2.2* This is the one I did not have the space for. *E2.3* Electrical Energy, to calculate you take the number of watts times the number of seconds. *E2.4* Alright. The formula to calculate Heat Energy. *E2.5* Heat Energy= Mass x Change in Temperature x Specific Heat.

T: Alright. *E2.6* You guys should all have this down. *P2.7* But if you do not have it, then make sure you have it. *P2.8* Formula for Efficiency.
... ... (continued the explanations)

T: The larger the number for the efficiency the more efficient it is. \textit{E2.20} To get a large number, you need? \textit{Q2.21}

S: Heat! \textit{R2.21}

T: A large amount of Heat Energy which means a large change in temperature, \textit{E2.22} but if you use a lot of Electrical Energy to make that Temperature change, then your efficiency is not going to be large because you have a large number dividing into the number. \textit{E2.23}

Table CDAT 4.18 Teacher Ben 2007-04-12P1 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
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</thead>
<tbody>
<tr>
<td>Explanation/Examples</td>
<td>$S_s'$ Explanation (NE)</td>
<td>$S_s'$ Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific Knowledge (SK)</td>
<td>Observation/ Data (OD)</td>
</tr>
<tr>
<td>Question/Prompt</td>
<td></td>
<td></td>
<td></td>
<td>2.21</td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>L3:Elaborative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L2:Corrective</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L1:Evaluative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\textbf{Number of Reasoning Components (#RC) in a Dialogue}

As shown in Figure 4.21 below, teacher Ben used of SK in 96.3\% of his discourse. Although this data represents a limited observation and analysis of his classroom instructions, the uses of SK and no uses of any other reasoning components when he communicated with his students is evident. As shown in the Dialogue 4.18 above, he seemed to try to make a connection with students’ experiences in E2.23 but he just used the concept of efficiency with its formula without any relevant observations or examples of experiences saying “you have a large number dividing into the number;” which is not an observation, data, or example but a kind of scientific concept.
Figure 4.21 RC used in teacher Ben’s dialogues

**Movements in Reasoning Components (MRC) between Dialogues**

Teacher Ben has 109 dialogues in his classroom discourse, and he showed almost no movement in reasoning components in a dialogue (#RC) and between dialogues. He shows only 5 movements that go to a different reasoning component out of 109 dialogues, which is .05 possibility of change, when a new dialogue starts. His characteristics in use of RCs represented by #RC and MRC are also connected to the fact that about 80% of his dialogues are less than 3 LODs with a single reasoning component of SK. Most of his dialogues are simple QRE patterns as discussed in the previous section about RQ1.

**#RC and MRC with teachers’ Feedback/Questions/Explanations**

Although Pearson’s correlation widely used does not assume normality, Spearman’s correlation test is more proper for the data of numbers of utterances since they are likely to be nonparametric. However, the data from teacher Ben’s dialogues still have too extreme distributions in #RC, EX, PD, and etc. (see Table 4.20). For example,
#RCs are 1 in 105 dialogues out of 109 and the number of PD utterances are 0 in 109 dialogues out of 109. Therefore, although the correlation estimates can be calculated, I decided not to report them here as results since they could be exaggerated and do not reflect what the data represent about the classroom discourse.

<table>
<thead>
<tr>
<th>LOD</th>
<th>#RC*</th>
<th>MRC*</th>
<th>EX</th>
<th>SK</th>
<th>OD</th>
<th>PD</th>
<th>T’s Qs</th>
<th>T’s Ex</th>
<th>L2 Feed</th>
<th>L3 Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>Dialogues</td>
<td>105</td>
<td>104</td>
<td>107</td>
<td>40</td>
<td>105</td>
<td>109</td>
<td>89</td>
<td>93</td>
<td>73</td>
<td>106</td>
</tr>
</tbody>
</table>

96.3% 95.4% 98.2% 36.7% 96.3% 100% 81.7% 85.3% 67% 97.2%

* #RC: Number of Reasoning Components in a dialogue, MRC: Movements in Reasoning Components between dialogues
** p < .01

**Teacher Cory**

**Use of Scientific Reasoning Components**

Teacher Cory has specific uses of reasoning components that start with SK and then move on to OD and PD through the entire classroom dialogues. After labs with a motion detector in classes 3 and 4, the utterances of OD and PD were used mostly as might be expected. However, even in classes 1, 2, and 3 that are lectures and reviews of problem solving, she used many utterances of OD and PD by connecting observations and data from their previous labs and experiments as shown in Table 4.21.
Table 4.20 Reasoning Components used by Teacher Cory

<table>
<thead>
<tr>
<th>Class</th>
<th>Episode Type</th>
<th>Content</th>
<th>EX*</th>
<th>SK*</th>
<th>OD*</th>
<th>PD*</th>
<th>RC used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Review PS Lecture</td>
<td>Speed</td>
<td>0</td>
<td>44</td>
<td>25</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distance Graph</td>
<td>0</td>
<td>3</td>
<td>66</td>
<td>42</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Complex Motion</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>37</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>PS together Lecture</td>
<td>Speed, Velocity</td>
<td>0</td>
<td>47</td>
<td>24</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Complex Motion</td>
<td>0</td>
<td>5</td>
<td>54</td>
<td>44</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Review PS Review Lab</td>
<td>Position Graph</td>
<td>5</td>
<td>15</td>
<td>16</td>
<td>27</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Complex Motion</td>
<td>0</td>
<td>0</td>
<td>73</td>
<td>28</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Review Lab</td>
<td>Complex Motion</td>
<td>2</td>
<td>7</td>
<td>38</td>
<td>29</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Position Graph</td>
<td>0</td>
<td>0</td>
<td>27</td>
<td>29</td>
<td>2</td>
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<tr>
<td>total</td>
<td></td>
<td></td>
<td>7</td>
<td>121</td>
<td>373</td>
<td>236</td>
<td>4</td>
</tr>
</tbody>
</table>

* EX: Students’ Experiences, SK: Scientific Knowledge, OD: Observation and Data, PD: Patterns from Data

In the Dialogue 4.19 below, teacher Cory provided an example observation in the beginning of the dialogue and cast a question (Q7.4) about the observation but the student answer was about the patterns of the observation (R7.4); Teacher Cory might be expecting the answer of “stop or not moving” with the question 7.4 but the student’s response R7.4 is about the line and slope. However, she returned to her questions about observations from Q7.7 again after a few questions and answers by making connections with the previous students’ responses about slopes (see Dialogue and Table CDAT 4.19).

Dialogue 4.19 Teacher Cory 2007-02-26P1 w/o CCT

T: So I have leg one here where I have a pretty good distance, E7.1 then I’m going to get to Giant Eagle. E7.2 This is the second leg of my trip. E7.3 What’s going to happen here to my motion? Q7.4

S: The line [inaudible]. R7.4

T: It’s going to… fQ7.5

S: Go down. R7.5

T: Go down? fQ7.6

S: Stay the same. R7.6
T: It’s going to stay the same because what am I no longer doing? \textit{fQ7.7}
S: You’re not moving. \textit{R7.7}
T: I’m not moving, but, what’s down here on the X? \textit{fQ7.8}
S: The time. \textit{R7.8}
T: Does time still pass when I’m at Giant Eagle, or does time stop, too? \textit{Q7.9}
S: It still passes. \textit{R7.9}
T: It’s still going. \textit{F7.9} So my distance isn’t going to change. \textit{E7.10} My distance is going to stay… \textit{Q7.10}
S: The same. \textit{R7.10}
T: The same. \textit{F7.10}

Table CDAT 4.19 Teacher Cory 2007-02-26P1 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
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</thead>
<tbody>
<tr>
<td>Explanation/Examples</td>
<td>Ss' Explanation (NE)</td>
<td>Ss' Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific knowledge (SK)</td>
</tr>
<tr>
<td>Question/Prompt</td>
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<td>7.4, 7.9, 7.10</td>
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<td></td>
</tr>
<tr>
<td>Student Response/Question</td>
<td>7.8, 7.9, 7.10</td>
<td>7.4, 7.5, 7.6, 7.7</td>
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<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>L3: Elaborative</td>
<td>7.8, 7.10</td>
<td>q7.7</td>
<td>q7.7</td>
</tr>
<tr>
<td></td>
<td>L2: Corrective</td>
<td>7.8, 7.10</td>
<td>q7.5, q7.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>L1: Evaluative</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Through the Dialogue 4.19 above, she used feedback questions and subsidiary questions often and that definitely lengthens the dialogue. While in the Dialogue 4.20 below, she started the dialogue with a question about the concept of speed (SK) and talked about the students’ misconception (NK) and then talked about patterns from the data (PD) again like the previous Dialogue 4.19.

Dialogue 4.20 Teacher Cory 2007-02-27P1 w/o CCT

T: What are velocities? What does velocity have to do with? \textit{Q2}
S: Nothing. \textit{R2}
T: We’ve been calculating it over and over again with V= distance divided by time. \textit{E2.1}
S: Speed.  
T: Speed. Good, Rachael; it has to do with our speed.  
Q2.2 And what does slope determine for us on a graph?  
S: Fast or slow?  
R2.2 T: Which is that same as…  
F2.1 S: Speed.  
R2.3 T: Speed. Ok.  
F2.3  
...... ....  
T: And you saw three different lines. E3.2 A lot of you told me one of the boats was faster because the line was longer. E3.3 Is that true?  
Q3.4 S: No.  
R3.4 T: No.  
F3.4 T: No. F3.4 We can extrapolate and make that line as long as we want on a graph. E3.5 If we want to know the average speed we’re going to look for…  
Q3.6 S: The slope.  
R3.6 T: The slope. F3.6 Give me another word for that slope. We’re looking at the…  
FQ3.7 S: Line?  
R3.7 T: How it’s what?  
FQ3.8 S: Inclined?  
R3.8 T: How steep it is, good. F3.8

Table CDAT 4.20 Teacher Cory 2007-02-27P1 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
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<tbody>
<tr>
<td></td>
<td>Ss’ Explanation (NE)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific Knowledge (SK)</td>
<td>Observation Data (OD)</td>
<td>Patterns from Data (PD)</td>
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<td>Explanation/Examples</td>
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<td>2.1</td>
<td>3.2</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>Question/Prompt</td>
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<td>2.2</td>
<td>3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student Response/Question</td>
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<td>2.1,2.2,2.3</td>
<td>3.6,3,7,3.8</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>1.3: Elaborative</td>
<td>q3.7,q3.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2: Corrective</td>
<td>3.4</td>
<td>2.1,2.3</td>
<td>3.6,3.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.1: Evaluative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the Dialogue 4.20, the questions Q3.6 and Q3.7 can be also questions about SK but they are connected to the data students collected (E3.2). Therefore, they were coded as PD in the Table CDAT 4.20.
**Number of Reasoning Components (#RC) in a Dialogue**

In the Dialogue 4.20 above, teacher Cory used one to three reasoning components in a dialogue and showed consistent movements through the dialogues. As shown in Figure 4.22, teacher Cory used OD and PD in a large amount of her dialogues showing movements of OD to PD, OD to SK, or OD to PD and EX or NK. Teacher Cory’s average #RC is 1.4 (SD = .61).

![Pie chart of Teacher Cory's RC]

**Figure 4.22 RC used in teacher Cory’s dialogues**

**Movements in Reasoning Components (MRC) between Dialogues**

Teacher Cory has 91 dialogues in her classroom discourse analyzed in this study and she also showed various movements in reasoning components when she moves on to a new dialogue. The Dialogues 4.21 below are a part of a lecture type of episode, and she explained the concept of complex motion by giving an example observation. In the
Dialogue 4.21 below, the dialogues 2, 3, 4 are about descriptions of the observation classified as OD in Table CDAT 4.21 below and dialogues 5 and 6 are about how speed and direction are represented in a motion graph so they belong to PD in reasoning components in CDAT (see Dialogue and Table CDAT 4.21).

Dialogue 4.21 Teacher Cory 2007-02-27P1 w/o CCT

T: What we’re going to do starting today is look at what we call complex motion when we look at how things change as things are moving, ok? E2 So used myself as an example, because yesterday I had to leave my house and I had to travel to Janesville. E2.1 And the way I do that from my house is I get on the expressway and go on the highway. E2.2 Nice, fast, no stops; E2.3 I was able to go pretty quickly, ok? E2.4 Then I got to Giant Eagle and what happened to my motion? Q2.5

S: It slowed down. R2.5

T: It slowed down and than it… fQ2.6

S: It stopped. R2.6

T: It stopped. F2.6 I was there for probably an hour, so I had a lull in my motion. E3 I had a point of no more motion in that car. E3.1 I stopped. E3.2 After an hour I got in my car and I drove down the street. E3.3 This time I had to go down Tusk, E3.4 and I went from Giant Eagle to Walgreens. E3.5 What would be different about this part of the motion from driving down Tusk, rather than this point if I was on the expressway? Q3.6

SS: [inaudible]. The expressway doesn’t have stop signs. R3.6

T: The expressway doesn’t have stop signs, so this one was a little bit slower, you think? fQ3.7

S: Yeah. R3.7

T: And after Walgreens, I turned around and I went back home. E3.8 So I could have a graph that looked like this. E4 I could show my average speed. E4.1 I could put times when I went fast on the expressway, times when I stopped, times when I went slower, and all the way back home. E4.2 Maybe this whole outing took me two hours. E4.3 I can take that entire distance I went, E4.4 maybe five miles and then five miles back home, which would be a total or what? Q4.5

SS: Ten. R4.5

T: Ten miles. F4.5 And I can do the two hours I was gone and what’s my distance divided by my time? Q4.6
S: Five?  
R 4.6  
T: Five.  
F 4.6  
So maybe my average speed would be five miles per hour,  
E 4.7  
but that includes this time that I’m in the grocery store not moving.  
E 4.8  
We know I wasn’t on the expressway doing five miles per hour.  
E 4.9  
So what we’re going to do today, when we talk about complex motion, we break it down into simple segments called legs.  
E 5  
How many ever heard that before?  
Q 5.1  
The leg of a journey?  
Q 5.2  
Have you ever heard that expression? No? Ok.  
Q 5.3  
When we’re talking about a leg we’re talking about one section at a time.  
E 5.4  
Our position graph.  
E 5.5  
When we’re talking about a leg we’re talking about one section at a time.  
E 5.6  
In my position graph, it might look like this.  
E 5.7  
Here’s my starting point, ok?  
E 5.8  
My reference point is home.  
E 5.9  
When I leave home and I go on the expressway I’m going pretty quick, right?  
E 5.10  
How do I know that line shows me a pretty good distance vs. time? A good speed?  
Q 6.4  
S: It has a good slope?  
R 6.4  
T: It has a good slope. Good, Daniel.  
F 6.4  
In fact, if I go even faster, which direction should my slope go?  
Q 6.5  
SS: To the right?  
R 6.5  
T: Maybe not straight up?  
R 6.6  
T: Maybe not straight up, but to the...  
Q 6.7  
S: Left.  
R 6.7  
T: Good.  
F 6.7

Table CDAT 4.21 Teacher Cory 2007-02-27P1 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Type</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation/Examples</td>
<td>Ss’ Explanation (NE)</td>
<td>2,1,2,2</td>
<td>Naïve Knowledge (NK)</td>
<td>Scientific Knowledge (SK)</td>
</tr>
<tr>
<td>Question/Prompt</td>
<td>2,5,3,6</td>
<td>4,5,4,6,5,2, 6,4,6,5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student Response/Question</td>
<td>2,6,3,6,3,7</td>
<td>4,5,4,6,6,8, 6,5,6,6,6,7</td>
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<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>1.3:Elaborative</td>
<td>q2.6,q3.7</td>
<td>q6.7</td>
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</tr>
<tr>
<td>1.2:Corrective</td>
<td>2,6</td>
<td>4,5,6,4,6,7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1:Evaluate</td>
<td>2,6</td>
<td>4,5,6,4,6,7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Although she did not show many changes in RCs whenever she moves on to a new dialogue, through the whole dialogues her movements in reasoning components (MRC) through the dialogues are quite persistent from OD to PD. Teacher Cory shows
31 movements that go to a different reasoning component out of 91 dialogues, which is .34 possibility of change (MRC), when a new dialogue starts.

**#RC and MRC with teachers’ Feedback/Questions/Explanations**

Table 4.22 below shows the Spearman’s correlations between each reasoning component and the number of reasoning components (#RC) in a dialogue, movements in reasoning components (MRC) between dialogues, teachers’ questions/explanations/feedback, and LOD. #RC has significant correlations only with the reasoning components of PD and the teacher’s utterances of explanations (Ex) while MRC does not have any significant relationships with reasoning components and teacher’s utterances. Teacher Cory spent a large amount of time to talk about OD therefore there are many dialogues with only OD and then sometimes moving on to PD when she explained the relationship.

<table>
<thead>
<tr>
<th></th>
<th>#RC*</th>
<th>MRC*</th>
<th>EX</th>
<th>SK</th>
<th>OD</th>
<th>PD</th>
<th>T’s Qs</th>
<th>T’s Ex</th>
<th>L2 Feed</th>
<th>L3 Feed</th>
<th>LOD</th>
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<tbody>
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<td>.388*</td>
<td>n/a</td>
<td>.035</td>
<td>.062</td>
<td>.629*</td>
<td>.385*</td>
<td>.174</td>
<td>.003</td>
<td>.273**</td>
<td></td>
</tr>
<tr>
<td>MRC</td>
<td></td>
<td>1</td>
<td>n/a</td>
<td>.072</td>
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<td>.178</td>
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<td>.162</td>
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<td>.005</td>
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</tr>
<tr>
<td>LOD</td>
<td>.273*</td>
<td>.059</td>
<td>n/a</td>
<td>.080</td>
<td>-.060</td>
<td>.390*</td>
<td>.470**</td>
<td>-.145</td>
<td>.656**</td>
<td>.565**</td>
<td>1</td>
</tr>
</tbody>
</table>

* #RC: Number of Reasoning Components in a dialogue, MRC: Movements in Reasoning Components between dialogues
** p < .01

MRC has only a significant correlation with #RC without any specific association with reasoning components and the teacher’s discourse types. The LOD in her dialogues has a significant correlation with only PD in RCs.
Teacher Daisy

Use of Scientific Reasoning Components

Teacher Daisy used many ODs, PDs, and SKs when she did reviews after labs with motion detectors as shown in Table 4.23 below. In her classroom discourse, each dialogue includes usually only one reasoning component and then she usually had movements in RCs from SK to OD and to PD or OD to PD through the dialogues.

Table 4.22 Reasoning Components used by Teacher Daisy

<table>
<thead>
<tr>
<th>Class</th>
<th>Episode Type</th>
<th>Content</th>
<th>EX*</th>
<th>SK*</th>
<th>OD*</th>
<th>PD*</th>
<th>RC used</th>
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<tbody>
<tr>
<td>1</td>
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<td>Acid and Bases</td>
<td>12</td>
<td>116</td>
<td>0</td>
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<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PH</td>
<td>0</td>
<td>0</td>
<td>40</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Review Lab</td>
<td>Speed and Velocity</td>
<td>19</td>
<td>49</td>
<td>9</td>
<td>119</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Motion Graph</td>
<td>0</td>
<td>39</td>
<td>32</td>
<td>32</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Lecture,</td>
<td>Speed, Acceleration</td>
<td>0</td>
<td>38</td>
<td>41</td>
<td>106</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Review Lab</td>
<td>Velocity, Graph</td>
<td>0</td>
<td>51</td>
<td>38</td>
<td>36</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Review PS</td>
<td>Velocity, Acceleration</td>
<td>0</td>
<td>11</td>
<td>6</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Motion Graph</td>
<td>0</td>
<td>19</td>
<td>5</td>
<td>0</td>
<td>2</td>
</tr>
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<td>5</td>
<td>Review PS</td>
<td>Velocity, Acceleration</td>
<td>0</td>
<td>5</td>
<td>9</td>
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<td>3</td>
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<td></td>
<td></td>
<td>Motion Graph</td>
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<td>22</td>
<td>0</td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

* EX: Students’ Experiences, SK: Scientific Knowledge, OD: Observation and Data, PD: Patterns from Data

In the Dialogue 4.22 below, the dialogue number 3 that started with Q3 is about the concept of velocity and then dialogues 4 to 6 are all about observations/data that students collected from previous lab activities. These dialogues were coded as separate dialogues not a long one because each one talked about a different part on the graph and the answers for the questions are unique.
Dialogue 4.22 Teacher Daisy 2008-04-07P4 w/o CCT

T: What’s the main difference between velocity and speed? Q3 Velocity has what? Q3.1
SS: Direction. R3.1
T: Allright, allright. F3.1 So if we find the slope of these three lines then we can calculate how fast our car was going to be able to look at velocity. E3.2
Allright, now let’s try to think about what’s actually happening within these graphs and then we’re going to do a little activity here with your points. E4
This first line that we’ve been working with, what’s happening to the distance in this first line? Q4.1 Where’s the car going? Q4.2
SS: Three. R4.2 / Acceleration. R4.3
T: First where’s it starting, right here. F4.3 Is it moving at the beginning? Q4.4
S: No. R4.4
T: No, F4.4 it started it at zero, then where did it go? Q5
SS: It went up. R5
T: It went up meaning it went further away from its original destination so that would be like starting the car at the top of the ramp. F5
.... .... ....
T: So now let’s think about this middle section here. P7 So the car is about two and a half meters at this specific point. E7.1 How far away is the car at this point over here on the right side? Q7.2
S: Two and half meters. R7.2
T: Two and a half meters F7.2 so if we were at two and a half meters here and we’re still at two and a half meters here was the car moving? Q7.3
SS: No. R7.3
T: No, F7.3 so what could we say the velocity was when we had our line go flat? Q7.4
S: Zero. R7.4
T: Zero. F7.4 The car was not moving, therefore there’s no velocity. E7.5
Table CDAT 4.22 Teacher Daisy 2008-04-07P4 w/o CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>Models/ Theories (MT)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ss' Explanation (NE)</td>
<td>Ss' Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Observation/ Data (OD)</td>
<td>Patterns from Data (PD)</td>
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<td>Explanation/Examples</td>
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<td></td>
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<tr>
<td>Question/Prompt</td>
<td></td>
<td>3,3,1</td>
<td></td>
<td>4,2,4,4,4,5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student Response/Question</td>
<td></td>
<td></td>
<td></td>
<td>2,2,7,3</td>
<td></td>
<td>7,4</td>
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<tr>
<td>Feedback</td>
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<td></td>
<td></td>
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<tr>
<td>L3:Elaborative</td>
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<td></td>
<td></td>
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<tr>
<td>L2:Corrective</td>
<td></td>
<td>3,1</td>
<td></td>
<td>4,3,7,2,7,3</td>
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<td>7,4</td>
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<tr>
<td>L1:Evaluative</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the Dialogue 4.22 above, the sequences of dialogues are typical patterns of teacher Daisy’s discourse in which each dialogue focuses on a single reasoning component and then there is a bridging dialogue like the seventh dialogue in the episode above that moves from OD to PD. Although she did not make use of many reasoning components in a dialogue, she exhibited movements from SK to OD or OD to PD through the dialogues.

**Number of Reasoning Components (#RC) in a Dialogue**

In the Dialogue 4.22 above, teacher Daisy mostly uses one reasoning component in a dialogue but the components she used in her whole classroom discourse vary; although 82 % of #RC is 1 in her dialogues, she used OD or PD in each dialogue as well as SK (see Figure 4.23 below) alternatively. Her #RC is 1.2 ($SD = .45$) which is not relatively high while her MRC is .43 which is relatively high, which means her overall use of RC through her classroom discourse is more varied than in each dialogue.
**Teacher Daisy’s # of Reasoning Components**

*#RC 1: 82%, 2: 16%, 3: 2%*

![Pie chart showing the distribution of reasoning components used by Teacher Daisy.](image)

Figure 4.23 RC used in teacher Daisy’s dialogues

**Movements in Reasoning Components (MRC) between Dialogues**

As shown in the example dialogues above, teacher Daisy persistently uses one RC in a dialogue through several dialogues and moves on to other RC by making connections in a dialogue (see Dialogue 4.22). Her major movements in RCs are from SK to OD, SK to OD and to PD, and OD to PD between dialogues and her MRC is .43 that shows 45 movements out of 104 dialogues.

**#RC and MRC with teachers’ Feedback/Questions/Explanations**

Table 4.24 shows the Spearman’s correlations between each reasoning component and the number of reasoning components (#RC) in a dialogue, movements in reasoning components (MRC) between dialogues, teachers’ questions/explanations/feedback, and LOD. Teacher Daisy’s #RC has significant correlations with the reasoning component OD and teacher’s utterances of questions ($p < .01$). When teacher Daisy used OD in her
dialogues, she often makes connections with other components by questioning and L2 feedback together and it makes LOD longer as well.

Table 4.23 Correlations between RCs, #RC, MRC, LOD, and teacher Daisy’s Utterances

<table>
<thead>
<tr>
<th></th>
<th>#RC*</th>
<th>MRC*</th>
<th>EX</th>
<th>SK</th>
<th>OD</th>
<th>PD</th>
<th>T’s Qs</th>
<th>T’s Ex</th>
<th>L2 Feed</th>
<th>L3 Feed</th>
<th>LOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>#RC</td>
<td>1</td>
<td>.344*</td>
<td>n/a</td>
<td>.091</td>
<td>.196*</td>
<td>.093</td>
<td>.234*</td>
<td>189</td>
<td>.274</td>
<td>.188</td>
<td>.335*</td>
</tr>
<tr>
<td>MRC</td>
<td>.344*</td>
<td>1</td>
<td>n/a</td>
<td>.070</td>
<td>.226*</td>
<td>.067</td>
<td>.254</td>
<td>.195**</td>
<td>.155</td>
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<td>.159</td>
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<tr>
<td>LOD</td>
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<td>.187</td>
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<td>.117</td>
<td>.652**</td>
<td>.169</td>
<td>.809**</td>
<td>.461**</td>
<td>1</td>
</tr>
</tbody>
</table>

* #RC: Number of Reasoning Components in a dialogue, MRC: Movements in Reasoning Components between dialogues
** p < .01

Teacher Eva

Use of Scientific Reasoning Components

Teacher Eva used only the reasoning components of OD and PD since every class had a lab section where her students did an experiment about waves with springs. Therefore the discourse in the classes is all review about waves focusing on phases, wavelength, frequency, and interference based on their class experiments. Teacher Eva showed various wave forms through the projector screen connected to her computer and asked several questions about waves. However, as discussed in the previous section, her dialogues are mostly simple QRE patterns extended once with L2 feedback questions and she did not extend LODs of her dialogues with various reasoning components as shown in Table 4.25.
In the Dialogues 4.23 below, teacher Eva focused on only the observations on the projector screen. If off topic utterances are disregarded marked with small numbers like F1.28, p1.29, or R1.31, the dialogues 1 and 2 turned out to be very simple QRE patterns with only a single reasoning component of OD as shown in the Table CDAT 4.23.

**Dialogue 4.23 Teacher Eva 2007-03-2P1 w/ CCT**

T1: One. Well if you’re frozen, F1.28 I guess you’d better make it [inaudible]. Zero. P1.29 Ok, so did most of them make it to a crest? P1.30

S: Nope. R1.30 cR1

T1: Here’s a crest; here’s a crest, that’s good. F1.30 Here’s a crest. Are there any other crests? Q1.31

S: There’s so many people on that one… R1.31

T1: I think we have some people frozen; F1.31 we’ve got a few people in a trough instead of a crest. F1.32

S: I went to a trough; R1.33 I didn’t realize… R1.34

T1: Ok, let’s try it again. P2 Let me individualize your cursors this time. P2.1 Let’s try it this time real quick. P2.2 We’re going to move to a trough. Q2.3

cR2 SS: Good, transfers. R2.4 Some people are still… R2.5 Yellow, I got an orange triangle. Oh, yeah. R2.6
T1: Go to a trough. 

S: Wait, where are we going? 

T1: To a trough; any trough you like. 

SS: Stop it. [class laughs]. I was making fun of you the other day. I’m sorry; I’m sorry. 

T1: Trough; you want to go to a trough. Ok, you need to find a trough. 

SS: What’s a trough? The lower point. It’s the negative crest; look at the arrow. There we go. Is that right? 


Table CDAT 4.23 Teacher Eva 2007-03-2P1 w/ CCT

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
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<td>Explanation/Examples</td>
<td>Sci’ Explanation (NE)</td>
<td>Sci’ Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific knowledge (SK)</td>
<td>Observation/Data (OD)</td>
</tr>
<tr>
<td>Question/Prompt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student Response/Question</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.30,2.3</td>
</tr>
<tr>
<td>Feedback</td>
<td>L.3: Elaborative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L.2: Corrective</td>
<td></td>
<td></td>
<td>1.30, q1.31, 2.17</td>
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</tr>
<tr>
<td></td>
<td>L.1: Evaluative</td>
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<td>1.32</td>
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</tbody>
</table>

She usually did not move on to other reasoning components (RCs) in a dialogue.

After the series of dialogues with the same RC of OD, she dealt with the other RC of PD in other dialogues. In the Dialogues 4.24 below, teacher Eva just focused on the PD with observations on the projector screen by showing to the students. After eliminating the redundant utterances from 4.4 to 4.14, the dialogues 4 and 5 also turned out to be very simple QRE patterns with RC of PD as shown in the Table CDAT 4.24 below.

Dialogue 4.24 Teacher Eva 2007-03-2P1 w/ CCT

T1: How about the one you would make if you shook your hand farther? So instead of shaking it like this, you shook it back and forth farther; you put more energy into your wave. Which one would you make?
SS: I’m getting confused. R4.4 Work now. Sweet. R4.5 It’s the one all the way to the right. R4.6 Ah. Gotcha. R4.7
Who is the… who’s this triangle? R4.8
It’s not a triangle, it’s a comma. R4.9 It keeps chasing me. R4.10
It’s trying to hang out over there. R4.11 cR4

T1: Get unlost. P4.12 If you’re lost, get unlost. P4.13 Which one is it going to be, then? P4.14
If you shake your hand back and forth farther, what’s that going to make get bigger? R4.15

S: It’s going to be the green one. R4.15

T1: It’s going to be the green one. F4.15
What does the green have, like bigger than the pink one? Q4.16

SS: Amplitude. R4.16

T1: Amplitude. F4.16 If you shake your hand back and forth then the amplitude here to here and here to here will be bigger. E4.17
When you shook it faster, like the purple, really, like the purple one, then you had a bigger what? Q5

SS: Frequency. R5

T1: Frequency. F5

S: Yes, ok. R5.1

T1: Good. F5 Let’s try some new waves, so sorry, you’re out of here. P6
Let’s try this one. Ok, let’s make one…P6.1

Table CDAT 4.24 Teacher Eva 2007-03-2P1 w/ CCT

<table>
<thead>
<tr>
<th>Discourse Reasoning</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
<th>Patterns from Data (OD)</th>
<th>Models/Theories (MT)</th>
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<tr>
<td>Explanation/Examples</td>
<td>S’s Explanation (NE)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific knowledge (SK)</td>
<td>Observation/</td>
<td>Patterns from Data (OD)</td>
<td>Models/Theories (MT)</td>
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<tr>
<td>Question/Prompt</td>
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<tr>
<td>Student Response/Question</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>L3:Elaborative</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L2:Corrective</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L1:Evaluative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Number of Reasoning Components (#RC) in a Dialogue**

As shown in the dialogues above, teacher Eva usually focuses on only one reasoning component in a dialogue. Figure 4.24 below shows the number of RCs teacher Eva used. She used only OD in 58% of her dialogues and only PD in 23% of her dialogues. In some dialogues, she showed movements from OD to PD or SK. Her average #RC is 1.24 (SD = .4).

![Teacher Eva's RC](image)

Figure 4.24 RC used in teacher Eva’s Dialogues

**Movements in Reasoning Components (MRC) between Dialogues**

Teacher Eva has just 31 dialogues in her classroom discourse analyzed in this study. The number of dialogues is relatively low compared to the classes’ time and other teachers’ numbers of dialogues. Since she used CCT almost all the time in the classes observed in this study, some of the students tried to have fun with the CCT and produced many off-topic utterances resulting in a much longer dialogue time. She had 14
movements out of 31 dialogues to a different reasoning component, which is .45 possibility of change when a new dialogue starts. However, the movements here between teacher Eva’s dialogues are clearly different from teacher Cory’s and Daisy’s. In teacher Eva’s classroom discourse, the connections between two consecutive dialogues rarely happened but they were often just two different dialogues with RCs of OD and PD separately.

**#RC and MRC with teachers’ Feedback/Questions/Explanations**

Table 4.26 shows the Spearman’s correlations between each reasoning component and the number of reasoning components (#RC) in a dialogue, movements in reasoning components (MRC) between dialogues, teachers’ questions/explanations/feedback, and LOD.

<table>
<thead>
<tr>
<th></th>
<th>#RC*</th>
<th>MRC*</th>
<th>EX</th>
<th>SK</th>
<th>OD</th>
<th>PD</th>
<th>T’s Qs</th>
<th>T’s Ex</th>
<th>L2 Feed</th>
<th>L3 Feed</th>
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<td>n/a</td>
<td>.106</td>
<td>.380**</td>
<td>-.023</td>
<td>.399**</td>
<td>.446**</td>
<td>.007</td>
<td>.140</td>
</tr>
<tr>
<td>MRC</td>
<td>.212</td>
<td>1</td>
<td>n/a</td>
<td>n/a</td>
<td>-.161</td>
<td>.194</td>
<td>-.101</td>
<td>-.052</td>
<td>.112</td>
<td>-.222</td>
<td>.000</td>
</tr>
<tr>
<td>LOD</td>
<td>.140</td>
<td>.000</td>
<td>n/a</td>
<td>n/a</td>
<td>.272</td>
<td>.280</td>
<td>.349</td>
<td>.472</td>
<td>.541</td>
<td>.381**</td>
<td>1</td>
</tr>
</tbody>
</table>

* #RC: Number of Reasoning Components in a dialogue, MRC: Movements in Reasoning Components between dialogues  
** p < .01

Since teacher Eva almost never used RCs of EX and SK, the correlations with other components could not be calculated or reported here. The relationships between #RC and teacher’s explanations (T’s Ex) indicates that when she explained scientific content, she often used more than two RCs. In addition, when she mentioned about PD,
she also often uttered another RC component when she explains about scientific content (see Table 4.26).

**Overall Comparison and Assertions for RQ2**

*Use of Reasoning Components (RC)*

Table 4.27 shows how many utterances teachers mentioned about each component of reasoning. Although the numbers can be affected by the type of class, content, class activities, and class time, this data can offer a brief description of the teachers’ use of inquiry components while they are talking. The five teachers have two or three lab sections, several review sections, and one or two lectures sections so they have similar amount of time for each type of lesson as shown and discussed in the previous sections.

<table>
<thead>
<tr>
<th>Teacher</th>
<th># Total Utterances</th>
<th>% of EX</th>
<th>% of SK</th>
<th>% of OD</th>
<th>% of PD</th>
</tr>
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<td>Ann</td>
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<td>48.83</td>
<td>33.59</td>
<td>10.35</td>
</tr>
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<td>Ben</td>
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<td>89.91</td>
<td>8.03</td>
<td>0.00</td>
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<tr>
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<td>745</td>
<td>0.94</td>
<td>16.24</td>
<td>50.07</td>
<td>31.68</td>
</tr>
<tr>
<td>Daisy</td>
<td>877</td>
<td>3.53</td>
<td>39.91</td>
<td>23.03</td>
<td>33.52</td>
</tr>
<tr>
<td>Eva</td>
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<td>0.61</td>
<td>63.30</td>
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<td>2897</td>
<td>2.90</td>
<td>38.49</td>
<td>34.14</td>
<td>24.20</td>
</tr>
</tbody>
</table>

The percentage of each reasoning component divided by the total number of reasoning utterances characterizes each teacher’s tendencies for using the inquiry
components. Although it is a small portion, teacher Ann uses more EX in the observed classes than the other teachers. Teacher Ben almost only uses SK while teacher Cory and Eva use more OD and PD since they had a review class after each lab. Teacher Ben also often had a review class after each lab, but still he used almost only SK utterances.

Figure 4.25 shows the total usage of each RC in each of the teacher’s dialogues. As discussed in the previous section that described each teacher’s characteristics, teacher Ben usually focused on SK, Cory had more emphasis on OD, Daisy’s on PD, and Eva’s on OD and PD.

Figure 4.25 Teachers’ use of Reasoning Components in Dialogues

Figure 4.25 shows that all the teachers did not use many EX for their lessons showing a small amount of EX utterances compared to other types of RCs. For the last several decades, many constructivists (von Glasersfeld, 1993; Yilmaz, 2008) have emphasized the critical roles of connecting students’ experiences to their learning. However, the results in this study indicate that the teachers rarely chose to use the
utterances of EX. The utterances as experiences (EX) coded were not limited to only direct students’ personal experiences but included any kinds of everyday life experiences, such as from movies, or from histories. However, not many teachers in this study tried to make connections between the content they taught and real life stories.

**Number of Reasoning Components (#RC) in a Dialogue**

Using more than two reasoning components in a dialogue is not easy, but not impossible. As shown and discussed in the previous sections, talking about students’ experience, scientific observations, or scientific knowledge together in a dialogue to support students’ understanding did not often happen in the classroom dialogues analyzed. From Figure 4.26, it can be observed that teacher Ann, Cory, and Daisy more often tried to use two or three reasoning components together in a dialogue than the other two teachers.

![Figure 4.26 Numbers of Dialogues in Levels of #RC used by teachers](image-url)
Although the use of only one RC represents a large portion of all the teachers’ dialogues, each dialogue has a different RC that varies with SK, OD, PD, or EX except teacher Ben who used only SK through almost all his dialogues. Table 4.28 below shows the average #RC that can represent the teachers’ classroom dialogues. For example, teacher Ben only used one component, SK (#RC = 1.05), in all his dialogues while some other teachers often used more than one components (#RCs > 1.40). However, the major reasoning components used varied by the teachers. Teacher Daisy and Ann mainly use SK and OD, but teacher Daisy often makes connections with PD while teacher Ann with SK. The average number of used reasoning components (#RC) indicates how many RCs the teachers used during the dialogue. Teacher Ben’s #RC has significant mean differences with all other teachers’ calculated by ANOVA (F = 9.98, p < .01).

<table>
<thead>
<tr>
<th>Teachers</th>
<th>Total # of Dialogues</th>
<th>Average #RC</th>
<th>SD</th>
<th>Std. Error</th>
<th>Major Used Components</th>
<th>Max # used Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ann</td>
<td>59</td>
<td><strong>1.46</strong></td>
<td>.652</td>
<td>.085</td>
<td>SK,OD,EX</td>
<td>3</td>
</tr>
<tr>
<td>Ben</td>
<td>109</td>
<td><strong>1.05</strong></td>
<td>.250</td>
<td>.024</td>
<td>SK</td>
<td>3</td>
</tr>
<tr>
<td>Cory</td>
<td>91</td>
<td><strong>1.40</strong></td>
<td>.612</td>
<td>.064</td>
<td>OD,PD,SK</td>
<td>4</td>
</tr>
<tr>
<td>Daisy</td>
<td>104</td>
<td><strong>1.20</strong></td>
<td>.449</td>
<td>.044</td>
<td>SK,OD,PD</td>
<td>3</td>
</tr>
<tr>
<td>Eva</td>
<td>31</td>
<td><strong>1.19</strong></td>
<td>.402</td>
<td>.072</td>
<td>OD,SK,PD</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>394</td>
<td>1.24</td>
<td>.505</td>
<td>.025</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

**Movements in Reasoning Components (MRC) between Dialogues**

Table 4.29 below shows the movements in reasoning components that indicates if the RC changes or not when a new dialogue starts. The data do not indicate how teachers used various RCs in their classroom discourse, but how often they tried to make
connections with other RCs among the dialogues. Movements in reasoning components (MRC) between dialogues can vary from SK to OD, SK to EX to OD, or OD to PD.

Table 4.28 MRC between Dialogues

<table>
<thead>
<tr>
<th>Teacher</th>
<th># Dialogues</th>
<th># Changes in RC</th>
<th>MRC</th>
<th>#RC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ann</td>
<td>59</td>
<td>27</td>
<td>0.46</td>
<td>1.46</td>
</tr>
<tr>
<td>Ben</td>
<td>109</td>
<td>5</td>
<td>0.05</td>
<td>1.05</td>
</tr>
<tr>
<td>Cory</td>
<td>91</td>
<td>31</td>
<td>0.34</td>
<td>1.40</td>
</tr>
<tr>
<td>Daisy</td>
<td>104</td>
<td>45</td>
<td>0.43</td>
<td>1.20</td>
</tr>
<tr>
<td>Eva</td>
<td>31</td>
<td>14</td>
<td>0.45</td>
<td>1.19</td>
</tr>
<tr>
<td></td>
<td>394</td>
<td>122</td>
<td>0.31</td>
<td>1.24</td>
</tr>
</tbody>
</table>

Although teacher Eva mostly used only two RCs, OD and PD, her MRC is relatively high since she often used OD or PD alternately in a dialogue in her classroom discourse. For example, the major focus of her classroom discourse was about what the students’ movements with their springs were (OD) and how the movements affected the waves’ phases, frequencies, and wavelengths (PD). Therefore, teacher Eva’s major MRC is reflected by alternating RCs between OD and PD. While, teacher Cory used relatively many RCs both in a dialogue and through dialogues but her MRC is slightly low compared to the other teachers’ since she tried to use more than one RC in a dialogue which is reflected by her #RC. Therefore both #RC and MRC characterize teachers’ classroom discursive dialogues with the aspect of scientific reasoning while LOD characterizes them with the aspect of discourse patterns.
#RC and MRC with teachers’ Feedback/Questions/Explanations and LOD

Table 4.30 below shows the correlations between each RC, #RC, MRC, and LOD that are computed with the whole data set. The correlations are different from the results from each teacher’s data showed in the previous sections. Since the numbers of sample dialogues is 394, it can be regarded as a large sample size so the correlations can be considered more general than the results from each individual teacher’s. None of the correlations between MRC and LOD from each teacher’s data was significant, but the correlations between them became significant when calculating with the overall data set.

Table 4.29 Spearman’s Correlations between #RC, MRC, teachers’ Utterances and LOD

<table>
<thead>
<tr>
<th></th>
<th>#RC</th>
<th>MRC</th>
<th>EX</th>
<th>SK</th>
<th>OD</th>
<th>PD</th>
<th>T’s Qs</th>
<th>L1 Feedback</th>
<th>L2 Feedback</th>
<th>L3 Feedback</th>
<th>Ss’ Utt</th>
<th>LOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>#RC</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRC</td>
<td>.420**</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>EX</td>
<td>.375**</td>
<td>.184**</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SK</td>
<td>.006</td>
<td>-.106*</td>
<td>.034</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>.371**</td>
<td>.247**</td>
<td>.013</td>
<td>-.438**</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PD</td>
<td>.408**</td>
<td>.280**</td>
<td>-.017</td>
<td>-.436**</td>
<td>.051</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T’s Qs</td>
<td>.297**</td>
<td>.267**</td>
<td>.107*</td>
<td>-.057</td>
<td>.268**</td>
<td>.299**</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1 Feedback</td>
<td>-.164**</td>
<td>-.251**</td>
<td>-.083</td>
<td>.115*</td>
<td>-.244**</td>
<td>-.228**</td>
<td>-.240**</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L2 Feedback</td>
<td>.303**</td>
<td>.240**</td>
<td>.075</td>
<td>.027</td>
<td>.345**</td>
<td>.237**</td>
<td>.489**</td>
<td>-.394**</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L3 Feedback</td>
<td>.228**</td>
<td>.111*</td>
<td>-.031</td>
<td>.003</td>
<td>.179**</td>
<td>.162**</td>
<td>.098</td>
<td>-.201**</td>
<td>-.241**</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ss’ Utt*</td>
<td>.364**</td>
<td>.253**</td>
<td>.065</td>
<td>-.014</td>
<td>.325**</td>
<td>.280**</td>
<td>.567**</td>
<td>-.261**</td>
<td>.662**</td>
<td>.447**</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>LOD</td>
<td>.406**</td>
<td>.229**</td>
<td>.094</td>
<td>.051</td>
<td>.300**</td>
<td>.300**</td>
<td>.603**</td>
<td>-.162**</td>
<td>.708**</td>
<td>.485**</td>
<td>.884*</td>
<td>1.000</td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01
* N = 394 dialogues, Ss’ Utt: Students’ utterances

#RC and MRC have significant relationships with all RCs except SK. This result means when teachers talked about OD, they often made connections with other RCs.
However, SK has negative significant correlations with OD and PD which means when teachers talk about SK they do not talk about other RCs such as OD, PD, or EX. Although scientific knowledge should be connected to the related observation/data, in some science classrooms observed in this study they are frequently dealt with separately. Teachers’ questions (T’s Qs), L2 and L3 feedback have positive significant correlations with LOD, #RC, MRC and OD and PD utterances. The correlation relationships are not cause and effect. Therefore, for example, the results can be interpreted in two ways: first, the more OD and PD utterances teachers make, the more questions and L2 or L3 feedback they utilize; or second, the more questions and L2 and L3 feedback they make, the more OD and PD they would talk about. However, with either interpretation, the LOD will be lengthened and expanded.

**Combined Model and Assertions**

Students’ responses also have positive significant correlations with #RC and MRC, which indicates if teachers use more various RCs in their dialogues, students’ utterances increase as shown in Table 4.30 above. Students can have more turns to answer or more students can respond to the teachers’ talk. The model in Figure 4.27 below shows the relationships between #RC, MRC, and students’ responses as well as possible students’ understandings. However, in many science classrooms, it is not easy to have more than two RCs in their classroom discourse although the teachers know the needs and effectiveness for their students’ learning. When the LOD model is combined
with the #RC model, it suggests how teachers can have more RCs in their dialogues and how to lengthen their dialogues.

The idea of #RC model is cone-shaped. When the LOD model wears this cone like a hat, it can explain the relationships between RCs and LOD. The dotted circles indicate the amount of RCs and students’ responses and they also imply the area of scientific reasoning and the capacity of students’ scientific understanding.

Figure 4.28 below shows the combined model with LOD model and Model of #RC. This model suggests several assertions associated with the results of RQ1 and RQ2. First, teachers’ subsidiary questions and feedback questions extend the length of dialogues. The model does not tell that every longer dialogue is better for students’ learning. However, in a longer dialogue, students might have more opportunities to think, consider more information about that specific content, and participate in active
interactions with their teachers with more reasoning components. Although the relationship between LOD and students’ learning/achievements is not established in this study, the longer and expanded dialogues are often recommended by researchers (Cazden, 2001; Gee, 2004; Hackling et al., 2010; Hicks, 1996).

Second, with more RCs, subsidiary questions and feedback questions can be more effective to lengthen the dialogues. When science teachers prepare their lesson plans, the reasoning components can provide ideas for subsidiary questions that can be about students’ experiences, observation/data, or patterns from the data due to the content and phases of inquiry. Building scientific knowledge itself can be a goal of science education as scientific literacy. However, without connections with OD, PD, or EX, enhancing
scientific literacy is very limited. Therefore, this result suggests that science teachers should prepare various subsidiary questions that make connections with various reasoning components. Moreover, the subsidiary questions can also serve as feedback questions in many cases when students reveal some misconceptions, need visual understanding, or require a direction for thought; the subsidiary questions can be the most effective feedback for students’ learning.

Third, knowledge about formative feedback can facilitate discursive dialogues in science classrooms. As shown in the results in the RQ1 section, L1 feedback often terminates the dialogue quickly since it is evaluative and normative while L3 feedback lengthens the dialogue with elaborative questions or opportunities to think more. On the other hand, L2 feedback can either terminate or extend LOD. Since L2 feedback is corrective, it usually terminates the dialogue with the right information about the question. However, in many cases, it comes with L3 feedback; teachers usually provide the information about the correctness of students’ answers first and then ask the reason for the students’ responses or give some elaborative information. Therefore, avoiding L1 feedback and using more L3 feedback is strongly recommended with appropriate use of L2 feedback.

Lastly, teachers’ understanding of scientific reasoning and the components of scientific inquiry should be practiced by communicating with their students. Knowing and understanding scientific reasoning and inquiry are quite different from supporting students’ scientific thinking. Typically, science teachers are considered as science experts who know scientific knowledge, reasoning, and methods. However, when science
teachers help students learn scientific thinking, reasoning, or knowledge, teachers should not just provide or deliver scientific content or methods but assist students to do or think by themselves. Therefore, teachers’ communication with their students should be practiced with feedback theory and RCs.
3. How CCT Affects Science Classroom Discourse

Two ways of using CCT in the classrooms are analyzed in this study. First, using CCT is for problem solving with Quick poll (QC), Learning Check (LC), or Activity Center (AC). The other way is for a lab activity using a motion detector connected to a calculator as a function of AC and teachers show students’ work through the projector screen by using Screen Capture (SC). After problem solving seatwork, teachers usually do a review while showing the students’ responses. In that case, teachers do not provide each question in the problem set and students do not answer each question again, but teachers give feedback or subsidiary questions and there are often no more additional students’ replies. Therefore, when counting teachers’ and students’ utterances as questions and answers, responses using CCT coded CR (Class Responses) were counted as a students’ response for each question and as a teachers’ question too in a dialogue.

All the data compared in this section are means of the numbers of utterances used in each dialogue (N = 394 dialogues) from the five teachers’ classroom discourse. Since the data are nonparametric (p < 0, Kolmogorov-Smirnov test), whether there is a significant mean difference or not was checked by the Kruskal-Willis test. In this statistical test, when the p values with Chi-squares are less than .01, significant mean differences exist.
**Teacher Ann**

*Teachers’ and Students’ Utterances and LOD*

Table 4.31 shows the differences in each number of utterances of the teachers, students, n/a, explanations, questions, levels of feedback, and LOD in teacher Ann’s dialogues which are compared when she used CCT with when she did not use it. No significant difference was found except teachers’ explanations (T’s Ex) that indicates teacher Ann did more explanations when she did not use CCT.

<table>
<thead>
<tr>
<th></th>
<th>0 = no CCT</th>
<th>1 = CCT</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Chi-Square</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ts’ Utt</strong></td>
<td>0</td>
<td>24</td>
<td></td>
<td>6.92</td>
<td>4.49</td>
<td>1.466</td>
<td>.226</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>35</td>
<td></td>
<td>6.17</td>
<td>5.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ss’ Utt</strong></td>
<td>0</td>
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<td></td>
<td>2.33</td>
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<td>.658</td>
<td>.417</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>35</td>
<td></td>
<td>2.69</td>
<td>2.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>N/A</strong></td>
<td>0</td>
<td>24</td>
<td></td>
<td>.75</td>
<td>1.26</td>
<td>.217</td>
<td>.641</td>
</tr>
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<td></td>
<td>1</td>
<td>35</td>
<td></td>
<td>1.17</td>
<td>2.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ts’ Ex</strong></td>
<td>0</td>
<td>24</td>
<td></td>
<td>.258</td>
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</tr>
<tr>
<td></td>
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<td>1.59</td>
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<td></td>
</tr>
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<td><strong>Ts’ Qs</strong></td>
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<td>2.29</td>
<td>1.51</td>
<td>.006</td>
<td>.936</td>
</tr>
<tr>
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<td>1</td>
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<td></td>
<td>2.91</td>
<td>3.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>L1 Feed</strong></td>
<td>0</td>
<td>24</td>
<td></td>
<td>.00</td>
<td>.00</td>
<td>2.129</td>
<td>.145</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>35</td>
<td></td>
<td>.14</td>
<td>.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>L2 Feed</strong></td>
<td>0</td>
<td>24</td>
<td></td>
<td>1.58</td>
<td>1.24</td>
<td>.039</td>
<td>.843</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>35</td>
<td></td>
<td>1.80</td>
<td>1.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>L3 Feed</strong></td>
<td>0</td>
<td>24</td>
<td></td>
<td>.46</td>
<td>.83</td>
<td>.190</td>
<td>.663</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>35</td>
<td></td>
<td>.31</td>
<td>.58</td>
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<td></td>
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<tr>
<td><strong>LOD</strong></td>
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<td>35</td>
<td></td>
<td>4.69</td>
<td>4.54</td>
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<td></td>
</tr>
</tbody>
</table>

CCT is a classroom network system that helps the interaction between a teacher and students to be effective and efficient. However, in teacher Ann’s classroom, CCT did
not affect the numbers of teachers’ and students’ utterances. Thus, it did not affect LODs of the dialogues.

**Use of Reasoning Components and #RC and MRC**

As shown in Table 4.32 below, there are significant mean differences between when teacher Ann used CCT and did not in #RC, MRC, and utterances of EX. The results indicate that she did more talk about more reasoning components when she did not use the technology. With combining the results from the previous section of RQ1 and RQ2 together, it can be interpreted that when teacher Ann explained scientific content, she often used RCs of OD, PD, or EX without using CCT for the explanations.

<table>
<thead>
<tr>
<th>Table 4.31 Comparison teacher Ann’s RC Utterances by use of CCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 = no CCT 1 = CCT</td>
</tr>
<tr>
<td>#RC</td>
</tr>
<tr>
<td>0</td>
</tr>
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<td>MRC</td>
</tr>
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<tr>
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</tr>
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<td>SK</td>
</tr>
<tr>
<td>0</td>
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<td>OD</td>
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</tr>
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<tr>
<td>1</td>
</tr>
</tbody>
</table>
Teacher Ben

Teachers’ and Students’ Utterances and LOD

Table 4.33 shows the differences in each number utterance of teachers, students, n/a, explanations, questions, levels of feedback, and LOD in teacher Ben’s dialogues between when he used CCT and when he did not use it. Almost all items have significant mean differences except L3 feedback but the means when he did not use CCT are all much higher. Effective communication does not mean less talk but teacher Ben showed much more utterances when he did not use CCT.

<table>
<thead>
<tr>
<th></th>
<th>0 = no CCT</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Chi-Square</th>
<th>Sig</th>
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<td>4.137</td>
<td>9.888</td>
<td>.002</td>
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<td>9.663</td>
<td>.002</td>
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These results indicate that teacher Ben did not use the information about the students’ learning status provided by CCT to extend the dialogues. Most of the time when
he used CCT, he did not ask any more questions after he sent a question to the students’ calculators as well as L2 or L3 feedback after he collected the students’ responses but he used more L1 evaluative feedback when he used CCT.

**Use of Reasoning Components and #RC and MRC**

Teacher Ben is fond of using only SK in his dialogues regardless of the lesson types. He used CCT only for reviews of problem solving and some of the problems were about OD rather than SK resulting in decreasing SK utterances (see Table 4.34). Teacher Ben reviewed the problem solving question by question without any elaborative feedback but with evaluative feedback. Therefore, he talked less about any RCs with CCT and the dialogues whose LODs are less than 3 increased.

<table>
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<th>Table 4.33 Comparison teacher Ben’s RC Utterances by use of CCT</th>
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**Teacher Cory**

**Teachers’ and Students’ Utterances and LOD**

Table 4.35 below shows the mean differences in the numbers of utterances of the teacher, students, n/a, explanations, questions, levels of feedback, and LOD in teacher Cory’s dialogues comparing when she used CCT and when she did not use it. Significant
differences exist in the comparisons of teachers’ explanations (T’s Ex), total teacher’s utterances (T’s Utt), and students’ utterances (Ss’ Utt). Teacher Cory’s explanations significantly decreased when she used CCT as well as the total teacher’s utterances. In addition, the students’ utterances (Ss’ Utt) increased significantly ($p < .05$) when she used CCT.

Table 4.34 Comparison teacher Cory’s Utterances by use of CCT

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Use of Reasoning Components and #RC and MRC

When teacher Cory used CCT, her utterances about SK increased significantly while the utterances of OD and PD decreased as shown in Table 4.36 below. The results are opposite from the ones for other teachers’ use in that they uttered more OD and PD when they used CCT. The differences can be explained by the differences in the teachers’ purposes for using CCT; teacher Cory used it to review basic concepts and formulas with
Quick Poll and Learning Check while other teachers use it for reviewing their previous lab activities with *Activity Center*.

Table 4.35 Comparison teacher Cory’s RC Utterances by use of CCT

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Teacher Daisy

Teachers’ and Students’ Utterances and LOD

Table 4.37 below shows the differences in each number of utterances of teachers, students, n/a, explanations, questions, levels of feedback, and LOD in teacher Daisy’s dialogues compared between when she used CCT and she did not use it. No significant mean differences were found except the N/A utterances; when teacher Daisy used CCT, the teacher and students spoke often about CCT and how to use it.
Table 4.36 Comparison teacher Daisy’s Utterances by use of CCT

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**Use of Reasoning Components and #RC and MRC**

Two significant mean differences were found in SK and PD between when teacher Daisy used CCT and when she did not (see Table 4.38 below). Typically when teacher Daisy explained scientific concepts coded as SK, she mostly did not use CCT. On the other hand, in many episodes, she displayed motion graphs on the projector screen and asked her students to find out the relationship between slopes and velocity or acceleration with activity center of CCT. Therefore the teacher and students had many utterances about PD when they used CCT. This showed the opposite use of CCT from teacher Cory’s in that teacher Cory used CCT for SK while teacher Daisy used it for OD and PD (see Table 4.35 and 4.37). However, when the two teachers used CCT, their explanations (T’s Ex) and total teachers’ utterances (T’s Utt) decreased although non-significantly for Daisy’s (see Table 4.36 and 4.38)
Table 4.37 Comparison teacher Daisy’s RC Utterances by use of CCT

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</table>

Teacher Eva

Teacher Eva used CCT in all her classes observed and analyzed in this study, so no comparison can be made regarding the use of CCT.

Analysis of Discourse in CCT and non CCT Classrooms

Questioning and Feedback

The teachers’ utterances in a dialogue in their classroom discourse do not show significant differences between CCT use and no CCT use in overall comparison (Chi-Square = 1.839, p = 0.175, see Table 4.60). However the numbers are likely to decrease (see Figure 4.29) since CCT was usually used for reviews of problem solving. In these instances CCT use did not spare much time for teachers’ talk alone, but resulted in time for the interaction with students. Therefore, for all teachers’ except teacher Ben, students’ talk is likely to be increased (see Figure 4.29) when they used CCT. Thus in the overall
comparison, the mean difference shows a trend towards significance \((Chi-Square = 3.347, p = 0.067, \text{see Table 4.39})\).

![Figure 4.29 Comparison teachers’ Utterances and Students’ in a Dialogue by use of CCT](image)

As shown in Figure 4.30 below, *Not Applicable (N/A)* utterances tend to increase when CCT was used except for teacher Ben. When they used CCT, teachers and students usually talked more about the technology and less about science content. However, in teacher Ben’s classes, students’ off-topic talk was high, but the students engaged slightly more in the classroom discourse when they used CCT. Teachers’ explanations are significantly decreased when they used CCT in all teacher’s comparison and overall comparison \((Chi-Square = 6.753, p = 0.009, \text{see Table 4.39})\). Teachers’ questions are likely to increase when they used CCT except teacher Ben’s as shown in Figure 4.30. Since the teachers used CCT for formative assessment in their classes, they often asked
additional subsidiary questions while they interacted with their students (Irving et al., 2009; Shirley, 2009).

![Figure 4.30 Comparison N/A, teachers’ Explanations, and Questions by use of CCT](image)

The changes in the utterances of each level of feedback do not show specific trends by the use of CCT (see Figure 4.31). Level of feedback strongly depends on teachers’ instructional methods. Teacher Ben already used much L1 and L2 feedback but when he used CCT he used more L1 feedback ($Chi-Square = 21.19, p < .01$) instead of L3 feedback. The other teachers do not show significant mean differences due to the use of CCT. Although I expected an increase in numbers of L3 feedback because teachers have more information about the students’ understanding with CCT, the data show that two of the teachers did provide more L2 feedback and less L3 feedback giving the information of whether the students’ answers are right or wrong without specific
elaborations (see Figure 4.31). Except teacher Ben, the other teachers almost never used L1 feedback. In their classroom dialogue, they provide at least corrective information when they responded to students’ answers or questions without evaluation or comparison of the students.

Figure 4.32 shows the ratios of the level of LOD’s in each of the teacher’s dialogues. Although the overall comparison does not show a significant difference in LOD (Chi-Square = .071, p < .79 see Table 4.39) compared by use of CCT. All the teachers except teacher Cory show a trend of increasing in smaller than 3 LOD and decreasing in larger than 3 LOD dialogues. Teacher Cory shows the opposite changes decreasing the number of dialogues that have smaller than 3 LOD and increasing the number of dialogues that have larger than LOD 3 when she used CCT (see Figure 4.32).
In each teacher’s comparison by the use of CCT, some common changes like increasing level 2 feedback, decreasing level 3 feedback, increasing dialogues of smaller than 3 LODs, and decreasing dialogues of larger than 3 LODs (except teacher Ben and Cory) were found. However, in overall comparison shown in Table 4.38 below, no significant difference was found except the decrease of teachers’ explanation and the increase students’ total utterances.
Table 4.38 Comparison all teachers’ Utterances by use of CCT

<table>
<thead>
<tr>
<th></th>
<th>0 = no CCT</th>
<th>1 = CCT</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Chi-Square</th>
<th>Sig</th>
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<td>250</td>
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<td></td>
<td></td>
<td>5.37</td>
<td>4.066</td>
<td></td>
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<tr>
<td>Ss’ Utt</td>
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<td>144</td>
<td>250</td>
<td>2.15</td>
<td>1.639</td>
<td>3.347</td>
<td>.067</td>
</tr>
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<td></td>
<td>2.48</td>
<td>1.968</td>
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<td>3.304</td>
<td>6.753</td>
<td>.009</td>
</tr>
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<td>1.632</td>
<td>1.213</td>
<td>.271</td>
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<td></td>
<td>2.03</td>
<td>1.905</td>
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<td></td>
</tr>
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<td>1.88</td>
<td>1.632</td>
<td>1.213</td>
<td>.271</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>2.03</td>
<td>1.905</td>
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<td></td>
</tr>
<tr>
<td>L2 Feed</td>
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<td>1</td>
<td>1.29</td>
<td>1.217</td>
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<td>.775</td>
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<td>1.36</td>
<td>1.347</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L3 Feed</td>
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<td>.30</td>
<td>.749</td>
<td>.727</td>
<td>.394</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>.33</td>
<td>.714</td>
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<td>.790</td>
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<td>3.69</td>
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</tr>
</tbody>
</table>

*Use of Reasoning Components*

Figure 4.33 below shows the comparisons of each teacher’s #RC in a dialogue and MRC between dialogues. Although the changes are not significant, #RCs are likely to decrease slightly when they used CCT since they did reviews of problem solving with CCT. Teachers dealt with one question at a dialogue with usually one RC except teacher Daisy. The movements in RCs when they start a new dialogue do not show significant changes compared by use of CCT. Overall, the use of CCT does not strongly have to do with the teachers’ use of more RCs in their dialogue or through the dialogues.
Figure 4.33 Comparison # RC and MRC by CCT

Figure 4.34 below shows the comparisons of the teachers’ use of reasoning components of SK, OD, and PD by the use of CCT.

Figure 4.34 Comparison RC used by CCT
Although the changes are not significant, it shows a trend of decreasing use of SK and increasing use of OD and PD since the teachers used CCT to present collected data such as motion graphs or wave phases except teacher Cory. Teacher Cory already did not use many reasoning component (RC) of SK but used many OD and PD in her classroom dialogues regardless of use of CCT. Teacher Cory often used CCT for reviews of problem solving with scientific concepts after some conversation related to OD and PD.

The overall comparisons of the use of reasoning components are shown in Table 4.40 below. Although the changes in #RC and MRC are not significant, the use of each utterances of SK, OD, PD, show significant mean differences used in a dialogue (see Table 4.40). Since the teachers often used CCT with their collected data to review a lab or PS, they talked less about SK but included more OD and PD in their dialogues.

<table>
<thead>
<tr>
<th>Table 4.39 Comparison all teachers’ Utterances by use of CCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 = no CCT 1 = CCT</td>
</tr>
<tr>
<td>#RC</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>MRC</td>
</tr>
<tr>
<td>0</td>
</tr>
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<tr>
<td>SK</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>OD</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>PD</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>
The visual display in Figure 4.35 shows a comparison of dialogue with and without CCT. As shown in Figure 4.35, when the teachers used CCT, they talk more about OD and PD than SK or they have more dialogues about OD and PD than the ones with SK.

The analysis of the science classroom discourse with CDAT reveals how the classroom discourse is characterized with respect to two aspects: first is the teachers’ questioning and use of feedback, and second is how the teachers and their students’ deal with reasoning components in their discourse. In this section of RQ3, the results from CDAT analyses show how the connected classroom technology affected the individual classroom discourse and what the common differences with and without CCT.
Chapter 5: Discussion and Implication

The results presented in chapter 4 exemplify a venture in discourse analysis to understand and improve discursive dialogues in science classrooms by providing visual and quantitative information from the qualitative data of classroom discourse. The differences in density and variety of classroom discursive dialogues do not mean better or worse discourse. However, the results by CDAT (Classroom Discourse Analytical Tool/Table) analysis can point to better discourse patterns for students’ science learning and reasoning. While a goal of science classes is likely to enact and understand concepts targeted through various science activities such as inquiry, problem solving, demonstration, or group projects, actual enactment of internalization of students’ experiences as their understanding and long-term memorized knowledge happens through the discursive dialogues with others (Vygotsky, 1978). One suggested implication from the results is that science teachers do not have to talk with regards to Scientific Knowledge alone to have productive classroom discourse. Conversely, providing students with as many opportunities as possible to talk with various reasoning components can be more productive.

In this chapter, the features of each teacher’s classroom discourse will be summarized as well as the overall description of how and what CDAT characterizes in classroom discourse. CDAT analysis has several notable benefits from the process of analysis and the resulting information. The benefits will be discussed in this chapter as well as a number of limitations. The process of analysis and the results suggest several
implications for overall science education, teaching and learning in secondary education, in-service and pre-service teacher education, and science educators and researchers. The limitations and implications propose several possible future studies that will also be presented in this chapter.

**Results Overview**

The CDAT itself produced some descriptive information about the dialogue analyzed. The information includes what the teacher and students utter, how the teacher responds, what scientific/everyday reasoning components are dealt with, and how the content information flows. With a few or many CDATs from a teacher’s classroom dialogues, some characteristics and trends in the discourse can be revealed as qualitative data analysis as shown in chapter 4. When quantitative data were collected from the teacher’s CDATs, some critical information that represents the classroom discourse with several aspects of questioning, feedback, and scientific reasoning can be obtained. The synthesized characteristics are represented by Length of Dialogue (LOD), number of Reasoning Components (#RC), and Movements in Reasoning Components (MRC). In this section, each teacher’s overall characteristics identified through the analysis with CDAT and how LOD, #RC, and MRC describe their classroom discourse will be presented first.

**Teachers’ Support Scientific Classroom Discourse**

Table 5.1 shows each teacher’s characteristics in their classroom discourse represented by the values of LOD, #RC, and MRC as well as comparisons and contrasts with each other teacher’s data. The interpretation of the values can reveal some narrative
information about the teachers’ classroom discourse. The main characteristics of teacher Ann’s classroom discourse are her attempts to connect students’ experience (EX) to the content that they are learning and frequent use of more than two reasoning components (RC) in a discursive dialogue as discussed in chapter 4. She used more questioning than other types of utterances like explanations or feedback.

Similarly, Table 5.1 reflects all the teachers’ overall classroom discourse characteristics. Teacher Ann’s average LOD is 4.69, which indicates 4.69 times turn changes between the teacher and students in a dialogue beyond simple QRE patterns by using subsidiary questions. Teacher Ben almost always used only SK and simple QRE patterns that is reflected in Table 5.1 with the values of LOD, #RC, and use of feedback. In his classrooms, many off topic students’ talk occurred as shown and discussed in chapter 4. He rarely used reasoning components of OD and PD even in a review time before or after a lab activity. Teacher Ben’s classroom discourse is an extreme case and the values in Table 5.1 reflects well his classroom characteristics with regards to his ways.
of questioning and feedback and dealing with reasoning components. On the other hand, teacher Cory used much level 3 feedback reflected by LOD and reasoning components of OD, PD and others reflected by #RC. Teacher Daisy and Eva included much OD and PD in their discourse but did not use often any other RCs reflected by #RC and MRC. Daisy and Eva used many L2 feedback rather than L3.

As discussed in chapter 3 and 4, the purpose of this study is to examine how well CDAT and the conceptual framework identify science classroom discourse with regards to teachers’ feedback and scientific reasoning. As accomplishment of the purpose and as shown and discussed in chapter 4, the results from the analysis with CDAT reflects the teachers’ classroom discourse qualitatively and quantitatively very well.

**LOD Model and #RC Model for Discursive Dialogue**

Although the purpose of this study is not to suggest better ways of achieving scientific discourse in a science classroom, two models (see Figure 5.1) were developed from the results about each research question. With these two models, I illustrated several assertions related to each research question. First, the role of subsidiary and feedback questions is critical in building a discursive dialogue. Many research studies on classroom discourse have reported simple QRE discourse patterns dominated in the classrooms analyzed and explained why the pattern is not recommended (Akerson & Hanuscin, 2007; Bybee, Carlson-Powell, & Trowbridge, 2008; Cazden, 2001; Duschl & Osborne, 2002; Gee, 2004; Hardy et al., 2010; Lemke, 1998). The LOD model provides an important clue about how to engage more students in the extensive discursive dialogues by using subsidiary questions and level 3 feedback. The result has an
agreement with the result from Nystrand and Gamoran’s (1991) study that students’ authentic engagement increases when teachers’ instructional discourse includes authentic questions, uptake, high-level evaluation with incorporation of previous answers into subsequent questions.

Second, the use of subsidiary questions and feedback questions must be considered together with the use of reasoning components. Without considering the use of RCs, teachers’ sub questions and feedback would be quite limited, but when teachers make use of various RCs such as EX, OD, or PD, students’ responses become more variable and increased in number.
Third, the use of level 1 feedback and some types of level 2 feedback usually terminates the discourse quickly. As shown in the LOD model and discussed in chapter 4, the evaluative feedback and corrective feedback with the right answer do not draw another students’ answers and more teachers’ feedback most of the time. Therefore, the use of level 1 feedback should be avoided in any situation like praise or reprimand with no reason, comparison of students, or vague information. The use of level 2 feedback is required in many situations, but it should be used with careful consideration like giving the right answer at the end of the dialogue, confirming what students’ understanding is, and using after or before level 3 feedback.

Lastly, in a dialogue or through dialogues, only talking about scientific knowledge (SK) does not engage the students in the dialogue more than 2 LODs. Although SK needs to be connected to OD, PD, and other RCs, teachers’ talk about SK usually does not extend the dialogues. When teachers talk SK such as scientific definitions or concepts without any connections to observations/data, it usually becomes conclusive and didactic.

Use of CCT for Classroom Discourse

The teachers whose classroom discourse were observed and analyzed in this study were the participants in the CCMS (Classroom Connectivity in Promoting Mathematics and Science Achievement) study and the classroom instructions happened in the first and second year of the study. They were all in the experimental group that received professional development once a year, provision of the technology, and used CCT (Connected Classroom Technology) at least once a week for their classroom teaching. A
variety of data has been produced by the teachers’ students like surveys, achievement tests, and student focus group interviews. Although the overall comparison in mathematics group showed significant increase in achievement test scores in the group of implementation of the technology (Irving et al., 2009), how it improves students’ learning and how it changes teachers’ instructional methods needs further study.

In science groups, from the student focus group (SFG) interviews and student survey analyses, there are some significant differences in their perception of learning, motivation, and engagement by teachers (Lee, Irving, Owens, Pape, & Shirley, 2011). Both how the use of CCT makes the differences and how teachers’ implementation creates the differences need to be studied more. In this study, the differences in the teachers’ classroom discourse revealed from the analysis with CDAT are clearly consistent with the results of previous studies. A big contribution of this study for other research studies that provide an intervention to science classrooms is that the analysis with CDAT can potentially identify how the intervention affects the classroom instructions/discourse. Depending on a study’s purposes, CDAT analyses could provide either dependent or independent variables.

For example, the use of CCT affects the teachers’ classroom discourse and CDAT analysis reveals how and what differences CCT can make in both the teacher’s discourse with individual students and the whole classroom discourse. As shown in Table 5.3 and discussed in chapter 4, the use of CCT commonly increases students’ opportunities to talk (Chi-Square = 3.347, p = .06), decreases teachers’ explanatory talk, and increases talk about OD and PD in their classroom discourse. This identification shown by CDAT
analyses can be a possible contribution for other educational technology related research studies as well.

Table 5.2 Overall Comparisons Differences in Discourse by Use of CCT

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<thead>
<tr>
<th></th>
<th>CCT</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Chi-Square</th>
<th>Sig</th>
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<tr>
<td>Ss’ Utt</td>
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<td>2.15</td>
<td>1.639</td>
<td>3.347</td>
<td>.067</td>
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<td>250</td>
<td>2.48</td>
<td>1.968</td>
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<tr>
<td>Ts’ Ex</td>
<td>0</td>
<td>144</td>
<td>2.28</td>
<td>3.304</td>
<td>6.753</td>
<td>.009</td>
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**Significance and Implications**

**Significance of this Study**

Although this study was conducted with the data from the CCMS study equipped with CCT in secondary science classrooms, the results shows that CDAT can be applied for any other intervention studies related to classroom discourse in secondary or higher science education. Although many quantitative data analyses can show significant differences, correlations, or effect sizes between the experimental groups and control groups, how the interventions make the differences is not revealed through these statistical comparisons. This CDAT analysis like other classroom discourse analysis tools can be a bridge between the intervention and the results as explanations about how it works.
The CDAT tool developed in this study has several significant aspects for analyses specifically of science classroom discourse. First, it shows visual information about the classroom discourse between a teacher and students. Second, although CDAT is a type of qualitative data analysis tool, it produces a variety of quantified data in the table CDAT. Many classroom discourse analytical tools like critical discourse analysis (CDA), CLASS 4.0, or semantic/thematic DA also use each teachers’ or students’ utterance as the unit of coding and a dialogue between a teacher and students as a unit of episode (Gee, 2004; Lemke, 1998; Nystrand & Gamoran, 1991). The information produced by the tools is rather descriptive and narrative. Also several classroom observation protocols evaluate classroom activities and discourse such as RTOP (Reformed Teaching Observation Protocol), Looking inside Classrooms, and Inquiry Science Observation Coding Sheet (ISOCS) (Brandon et al., 2008; Piburn et al., 2000; Weiss et al., 2003). They all use Likert-type evaluative and summative questionnaires. In this section, how CDAT is considerably different from other discourse analytical tools and classroom observation protocols will be presented.

**CDAT: Visualized and Quantified Information**

The first major noteworthy feature of CDAT analysis developed in this study is visualized information about dialogues in science classrooms. As shown and discussed at length in Chapter 4, a CDAT is for one dialogue or a few dialogues. At a glimpse, CDAT makes available a variety of descriptive information about the dialogue between the teacher and students. For example, the following descriptive information could be understood from the Table 5.4. First the dialogue is about OD (Observation and Data)
and PD (Patterns from Data); second the teacher received students’ responses by using some feedback questions, she provided some explanations or examples; and there was no off topic talk.

Table 5.3 CDAT Teacher Cory 2007-02-26P1 w/o CCT

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<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
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<th>Scientific Reasoning (SR)</th>
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<td>Ss' Experience (EX)</td>
<td>Naive Knowledge (NK)</td>
<td>Scientific knowledge (SK)</td>
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<td></td>
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<tr>
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<td></td>
<td></td>
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<td>7.4,7.9,7.10</td>
</tr>
<tr>
<td>Student Response/Question</td>
<td></td>
<td></td>
<td></td>
<td>7.8,7.9,7.10</td>
</tr>
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<td></td>
<td></td>
<td>q7.8</td>
</tr>
<tr>
<td></td>
<td>L2:Corrective</td>
<td></td>
<td></td>
<td>7.9,7.10</td>
</tr>
<tr>
<td></td>
<td>L1:Evaluative</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If several consecutive CDATs are shown, more specific information about the classroom discourse can be described as well. For example, the series of CDATs can tell what reasoning components the teacher prefers to use, how she or he deals with students’ answers with levels of feedback, if there is a specific discourse pattern among reasoning components or questioning and feedback through the dialogues.

The second major significance of CDAT is that it provides a variety of quantified information about the dialogues and classroom discourse. CDAT deals with only the classroom talk between a teacher and the students about the scientific content dealt with in these classes, but it does not include the individual talk between a teacher and a student and student-student talk. If there are students’ or teacher’s off-topic talk during the dialogue, they are classified into N/A in the CDAT. Therefore, when teacher’s and students’ utterances are counted, all off-topic talk is removed into N/A cell in CDAT first.
All the teacher’s and students’ utterances except N/A are classified into appropriate RCs and discourse types and counted separately and as a whole. With the components identified in the CDAT, each counted number represents specific information about a dialogue and the series of classroom dialogues.

The counted data include the numbers of each reasoning component used, the numbers of questions and explanations used, the numbers of each levels of feedback, and the numbers of students’ responses in a dialogue and total numbers through the classes analyzed. With the quantified data, researchers can expand the data analysis with various statistical methods like mean comparisons, ANOVA, correlations, or structural equation modeling with other quantified data sets. In this study, I have developed several representative average values of the classroom discourse; length of dialogue (LOD), numbers of reasoning components (#RC), and movements in reasoning components (MRC). However, researchers still can create other representative, quantified, and manipulated values such as the ratio of teacher’s and students’ utterances, the ratio of teacher’s questions and feedback, or the ratio of each RC used from the CDAT analysis.

These two visualized and quantified data sets can expand a research study’s capacity as synthesized research methods with qualitative data regarding classroom discourse observations. The former provides some descriptive information about the classroom dialogues as qualitative data and the latter offers a variety of statistical information as quantitative data. Furthermore, the quantified data provide a connection with other statistical data sets provided by surveys or achievement tests.
Formative Assessment for Teachers’ Instructional Practice

The information from CDAT analysis can be evaluated by researchers or stakeholders. However, the data are neither evaluative nor normative estimates rather they are descriptive and formative assessment for teachers’ instructional practice. Purposes of formative assessment are first to understand students’ understanding and second to provide formative feedback. Since the CDAT describes how the teachers lead their classroom discourse as assessments and provides how they improve their discourse in relation to discursive and scientific features, it can be a tool for formative assessment of science teachers’ classroom discourse.

For Teaching and Learning Science

The purpose of this study to develop a classroom discourse analytical tool resulted in the CDAT with instructions and exemplars. However, through the analysis of the classroom discourse data from five teachers’ classroom discourse, this study has also resulted in several conceptual or empirical models about science/scientific classroom discourse. With the models, the methods of CDAT analysis and the information from the analysis provide various implications for teaching and learning science in secondary education.

For Science Teachers

As discussed previously, a CDAT analysis provides science teachers with two aspects of descriptive information for their classroom discourse: first is how they support the productive classroom discourse, and second is how they deal with scientific reasoning components. With the model bridge between student’s EDR (Everyday Reasoning) and
SR (Scientific Reasoning) (Figure 3.3), teachers can improve their understanding of scientific reasoning and the ways of improving students’ scientific understanding and reasoning. Furthermore, the resulting descriptive and quantified information by CDAT analysis would provide the teachers with some formative feedback for their classroom discourse practice as a self-evaluation tool.

With the LOD model (Figure 4.16) and model of #RC, science teachers can have ideas of how to improve their classroom discourse to be scientific and to engage their students more in discourse. Since the information includes what types of questioning and feedback were used, what reasoning components were used, and how they make connections among RCs and students’ thinking, the science teachers could receive some feedback about how and what they need to improve in their classroom discourse. With that self-evaluation and practice, the science teachers will improve not only in understanding about scientific reasoning and formative feedback but also in understanding how to support their students’ scientific reasoning skills and scientific understanding.

For Pre-Service Science Teachers

Many science education institutes use evaluative assessment for their pre-service science teachers’ teaching practices based on NCATE/NSTA criteria. When the pre-service science teachers do micro teaching or teaching practice in the schools assigned to them, they receive considerable feedback from their mentor teachers, advisors, or even their classmates about their teaching. Not all the feedback is evaluative or subjective, but it can be narrative with their own subjective criteria. The descriptive information
produced by CDAT about their classroom discourse with visualized and quantified data that can be more effective for them to learn how they talk and interact with their students and how they deal with scientific reasoning components.

The CDAT can also be used as a peer assessment tool for pre-service teacher micro teaching practice. While they are doing a CDAT analysis about another’s instructional discourse, peer assessors would have to think about the components in the CDAT such as reasoning components, levels of feedback, questions and explanations, and others. Through the process, pre-service teachers will gain more confidence on understanding about reasoning components, questioning, and how to provide formative feedback. By receiving results of the CDAT analysis done by others, the pre-service teachers will have feedback and enlightenment from receiving the result. Use of the CDAT can also serve as a practice in delivering formative feedback.

When teachers and pre-service teachers do prepare a lesson plan, they put much consideration about objectives, science content, lab activities, or group activities, but they often do not consider how to interact with their students regarding what their questions will be, what the students’ answers will be, and what their feedback will be. With a CDAT, and the models developed in this study, science teachers and pre-service science teachers will be able to practice preparing questions, subsidiary questions, and feedback utterances as well as practice predicting students’ answers and giving appropriate feedback in the frame of scientific reasoning and inquiry. After preparing a lesson using a CDAT, teachers will be more aware of their questioning in the process and have the potential for improving instruction.
For Science Educators

As discussed above, CDAT analysis produces various types of qualitative and quantitative data representing teachers’ classroom discourse characteristics regarding feedback theories and scientific reasoning. With the data, a science education research study can expand its capacity of doing research not solely for the studies of classroom discourse but for the studies of scientific reasoning, scientific understanding, professional development, educational technology, or formative assessment. Due to the studies’ purposes and methodologies, the data from CDAT analysis can be either dependent or independent variables.

Although the CDAT process was developed for the classroom dialogues between a teacher and students, it can also be used for any types of science related discourse such as student small group discussion, a teacher with an individual student, or students’ presentations. With a revision of CDAT due to a particular study’s purpose and methodology, it can show flows of information regarding what (i.e. reasoning components), how (i.e. questioning and feedback), and where (i.e. from a teacher to students or students to a teacher).

Limitations

Limited Number of Sample

Five physical science teachers were chosen for this study. They were participants in the CCMS study and completed the first and second year professional development. All the teachers’ classroom instruction was observed for two or three consecutive days
each year and all the observations were videotaped and transcribed. The numbers of their classes analyzed in this study are just four or five out of hundreds of their academic year classes. Therefore, the classes analyzed in this study are just a small part of the teachers’ instructional practices, and the analysis does not tell everything about their instructional, discursive, or pedagogical characteristics. However, the purposes of this study are to develop a conceptual framework and an analytical tool for science classroom discourse, and to examine how the framework and tool identify the classroom discourse and teachers’ feedback practice. Through the analyses of the small amount of the teachers’ classroom discourse, this study shows that CDAT analysis can be a stethoscope to diagnose their discourse patterns and use of scientific reasoning.

However, the limited classroom observations also means limited lesson types from the teachers’ whole year or semester of instruction. Although, all the observations included at least one or two lab sections, more than three review sections, and more than two problem solving sections in each teacher’s classroom, they might have other types of classes such as small group discussions, students’ presentations, or whole class students’ discussions. In different types of classes, the teachers might show different types of discourse patterns or reasoning components. Therefore, CDAT analysis does not tell what the teacher’s typical discourse patterns or use of scientific reasoning phases are, but it can tell what the teacher’s specific characteristics of discourse pattern or reasoning components are in the observed classes. Additionally, CDAT analysis can profile differences in discourse pattern due to the class type.
Although the data of teachers’ background, interviews, and surveys as well as students’ characteristics, interviews, and surveys have been collected through the CCMS study, this dissertation study focuses only on classroom observation data to identify characteristics of each teacher’s classroom discourse. The other data might give some information that explains why the teachers did this or that and details about their students’ behaviors building trustworthiness by data triangulation. However, the students’ and teachers’ characteristics were excluded from this study because they might give some prejudices when I analyzed their classroom activities and discourse. This might serve as a limitation of this study since there might not be enough explanations about the results as qualitative research.

The transcribers in this study tried to transcribe all the verbal communication in those observation videos. The recorded voices with a camcorder and a microphone are usually clear for only teachers’ talk and the students’ responses but students’ responses were sometimes not clear or audible. Also the conversations were not recorded or transcribed when the teachers talked with individuals or students in a small group. Therefore, this study does not include all the discourse in the classrooms, but only the discourse between a teacher and the whole class defined as classroom discourse in Chapter 3. The teachers might have talked to individuals or small groups in different ways from their utterances to the whole class, but in this study the CDAT analysis included the whole-class discourse only. As discussed in the previous section, CDAT potentially can be used for small-group discussions or discourse between a teacher and individuals or a small group with specific research designs and revisions for those research studies.
**Validity, Reliability or Trustworthiness and Triangulations**

Although the concepts of validity and reliability are a quality of quantitative research and cannot be applied in the same manner for qualitative research study, the terminologies can be replaced by trustworthiness (Lincoln & Guba, 1985). Guba (1985) proposed four criteria considered by qualitative researchers in pursuit of a trustworthy study by addressing similar issues in quantitative research: a) credibility (in preference to internal validity), b) transferability (in preference to external validity/generalizability), c) dependability (in preference to reliability) d) confirmability (in preference to objectivity). If trustworthiness can be maximized, more credible and defensible results may lead to generalizability for high quality qualitative research (Lincoln & Guba, 1985; Strauss & Corbin, 1997). Triangulation is typically a strategy for improving the trustworthiness and generalizability of a qualitative research study or evaluation of findings corresponded to validity and reliability in quantitative research (Lincoln & Guba, 1985; Strauss & Corbin, 1997). In this section, some limitations in concern of building robust trustworthiness (or validity and reliability) and triangulation will be presented.

First, dependability is one criterion of trustworthiness that describes how repeatable the research methodology would be for another researcher. Since the framework, analytical tool, and the coding scheme and rubric were developed by one researcher, this study could have some limitations in having repeatable research methodology with robust validity and reliability. In this study a well-defined coding scheme is fundamentally critical for the all results produced. Although the coding process
has considerable inter-rater reliability ($Kappa = .686$) among two coders, some possible limitations need to be discussed related to the coding scheme and rubrics.

In this study, the unit of episode is a discursive dialogue between a teacher and the class. One dialogue starts with a new question and it ends when another dialogue starts with another new question. Therefore, the definition and criteria of a new question is critical, but it is sometimes very sophisticated. A new question is distinguished by noting that the answers to this question are uniquely different from the previous one. However, when the answers of a new question in a dialogue are responses to the answer of the first question, the new question still belongs to the same dialogue. The determination of a new dialogue is usually clear, but it is sometimes really controversial. Therefore, more practice and reliability with some other researchers in that coding is needed.

As also discussed in Chapter 3 in detail, the second difficult part in the coding scheme is identifying a subsidiary question that is also related to determining a new question to determine a dialogue. A subsidiary question is defined as a question that has a part answer of the former question. For example, the question “It deals with speed, but what else?” has a partial answer of the previous question, which is classified as a subsidiary question. However, in the dialogue 5.1 below, Q3 is related to the previous Q2, but it does not have partial or the same answers so Q3 is classified as a new question.

Dialogue 5.1 Teacher Ann 2007-04-27P3

T: for velocity to change are what two things? Q2
S: Velocity. R2
T: What two things make up velocity? \textit{Q2.1}
S: Speed. \textit{R2.1}
T: Speed or... \textit{fQ2.2}
S: Direction. \textit{R2.2}
T: Direction. \textit{F2.2} So can you tell me the two places on this graph where he changed velocity? \textit{Q3}
S: In the middle. \textit{R3}

Although the detailed definitions, descriptions and exemplars were discussed in Chapter 3, the coding scheme and criteria need to be practiced more for the better reliability as well as with the codes of reasoning components and levels of feedback.

Second, generalizability with more defensible results can be improved through triangulation with various sources of data (Lincoln & Guba, 1985). Although the aimed results are how well CDAT analysis characterizes the classroom discourse and teachers’ discourse pattern, several representative values are created, LOD, #RC, MRC, and others. I do not say the longer dialogues (LOD) with various reasoning components (#RC) are better for students’ learning or even that they are more scientific. Further research is needed to clarify how the results from the CDAT analysis of classroom discourse impacts students’ learning and scientific understanding and reasoning skills. Through the literature reviews and building a theoretical framework, the theories, research scopes, and related research studies were reviewed for the validation of the research methodology and coding scheme. However, if other data such as students’ and teachers’ interviews and surveys are analyzed and compared with this study’s results for the triangulation, the results would be more defensible and credible.
Another criterion of trustworthiness is conformability, corresponding to validity, which can be increased through communication with other researchers and experts in scientific reasoning and discourse fields by providing diagrams to demonstrate an “audit trail” (Lincoln & Guba, 1985). Another possible way to build a robust validity is conducting pre- and post-tests to investigate the students’ achievement in scientific understanding and reasoning skill with strongly validated instruments.

**Demonstration of Students’ Achievement and Reasoning Skills**

Teachers’ talk in their classrooms is believed to have an important impact on students’ leaning, reasoning skills, and even motivation and learning strategies. This study resulted in two aspects of classroom discourse; one is about teachers’ feedback skills and the other is teachers’ use of scientific reasoning components. I assume that increasing teachers’ feedback skill would have effects on students’ learning including motivations and strategies. Furthermore, teachers’ use of scientific reasoning components in their discourse should have positive impacts on the students’ learning science and scientific reasoning skills.

Although, the CCMS study collected the data sets of students’ interviews and surveys, the data are not specified for the classroom discourse. We can still investigate the relationships between the results in this study and the data sets, but that would be much beyond the scope of this study and will be evaluated in the future. For the students’ achievement test, I hypothesize that there is strong and significant relationships between teachers’ discourse patterns and the use of reasoning components and students’ scientific understanding and reasoning skills. However, the tests administrated in the CCMS study
did not include a scale to measure scientific reasoning learned in the classrooms to be compared with the data analyzed in this study. The achievement data gathered from students in this study represented general science knowledge. A future study should include more diagnostic science content tests to target student learning gains aligned with teacher instruction.

**Future Study**

*Refinements of the Coding Scheme*

The methodology and results presented in this dissertation study can be extended in a number of different ways. As discussed in the previous section, the definitions of the codes and practical exemplars need to be developed more. The determination of one discursive dialogue as unit of episode should be refined with various classroom discourse resources by several researchers. Also, the codes redefined in this study for the CDAT coding will be continually refined as additional work is done with a broader sample size and additional researchers. With refinements of coding scheme and codes, an even more credible model may be developed.

Another area of the coding scheme to be refined is the category of teachers’ questioning types, subsidiary questions and feedback questions. Both questions have commonalities and also clearly different aspects. In this study, if a question has both aspects, it was coded into feedback questions. However, since each question has its own impacts on forming the dialogue and different purposes, how to combine, how to separate the two question types, and how to interpret its impacts need to be studied more.
Although the determination of each level of teacher feedback is relatively clearer, sharper distinction or having more levels of feedback also need to be considered. Since level 1 feedback includes “no feedback,” “vague,” or “misleading,” feedback and they have different aspects from evaluative feedback, how researchers deal with those feedback types should be considered. Level 2 feedback can have variety in either verbal or nonverbal expressions. For example, only repetition of students’ answers could have different meanings due to the circumstance; it can sometimes mean the answer is right, but it can also mean it is wrong or even has no meaning at all. Therefore refinements of the levels of feedback with clear exemplars need to be studied more. Lastly, the improvements of the clarifications of each reasoning component with specific content area can be included in a future study.

Extension to Reasoning Components of Model/Theories and Naïve Explanations

CDAT includes the reasoning components of scientific model/theories (MT) and students’ naïve explanations (NE). However, the utterances of these two components were never coded in this study. Some possible explanations about this issue can be discussed and studied in a future study. First, the classes observed did not have any sections for students to explain something. If the classes included project-based learning and students had presentation time about their projects, talk about theories and models would increase. Second, none of the teachers in this study asked about any models/theories. Although they have lab activities and class reviews about the labs, the teachers did not provide opportunities for their students to explain based on models or
theories. The lack of attention to models and theories is also due to the class type and the content.

With specific a content area and specific types of lesson including students’ presentations, the coding area in CDAT can be extended to model/theories (MT) and students’ naïve explanations (NE). It might need certain types of professional development for the science teachers related to questioning types, scientific reasoning components, and reasoning skills. However, the intervention could be intended to increase questions and answers in the components of MT. Therefore, the research methodologies and purposes could be focused on how teachers support students’ connections between MT and observation/data and the students’ experiences or other components in CDAT.

**CDAT Analysis for Student-Student Talk**

Another possible extension of this study, the use of CDAT analysis, is for student-student discourse. Various types of student-student talk exist in science classrooms, such as small group talk, presentations, and argumentation practice. CDAT analysis can also be used for the students’ discourse by revising due to the study’s purpose and methodology. For example, for a student’s presentation, the teacher’s part in a CDAT can be replaced with the presenter student. For a discussion or debate between students, several CDATs can be used for each group.

These types of studies can expand the capacity of CDAT analysis to investigate how students use various reasoning components, how they make connections with other components, or how they respond to other students’ questions. CDAT can be also used
for students’ written explanations to examine what reasoning components they choose and how they use them through the phrases or sentences in their writings.

**Students’ Achievement and Reasoning Skills**

The most promising and possible future research study is to explore the relationships between teachers’ discourse patterns revealed by CDAT and students’ achievement or reasoning skills. With specific content area and with the same grade student random samples, a study can investigate the relationships without any interventions. It could be a pilot study for the next step that provides the teachers with an intervention about CDAT analysis, scientific reasoning, implementation of educational technology, or any types of professional development related to the study’s purposes.

Pre- or posttest instruments can be obtained or developed for specific instructional sequences. With these quantitative data, researchers would be able to have various statistical explorations by comparing the data produced by CDAT such as correlations, regressions, multiple regressions, or even structural equation modeling that reveal causal relationships among the variables. Besides the statistical data analysis, the researcher can collect much descriptive information about the discourse and how the specific discourse is connected to the students’ achievements and increased reasoning skills. Other areas that can be compared with CDAT analysis are students’ motivations, attitudes, and learning strategies. One example instruments is MSLQ that examines students’ motivations, metacognitions, attitudes, and learning strategies with high validity and reliabilities.
Enhancing Teachers’ Feedback Practice and Reasoning Skills

CDAT can be used for science teachers as a self-evaluation tool for their classroom discourse in a research study regarding teacher development. Through that practice of self- or peer evaluation with CDAT, the teachers can expand their capacity and understanding of using each scientific reasoning component and types of questions and feedback. Professional development (PD) for science teachers usually focuses on more scientific activities and experiments. With CDAT, however, any PD can deal with how to support their student with the observation/data they collected with descriptive information about their discourse. The PD also provides the teachers with the opportunities to create various subsidiary questions and practice questioning and providing high levels of feedback.

CDAT itself does not have any evaluation but the diagnostic information produced can be assessed by the teachers or others based on the models developed in this study. The teachers could also improve that information to consider and explain how they would make instructional decisions. The use of CDAT as an assessment tool for the teachers’ discourse would demonstrate if the teachers have the capacity for identifying connections between reasoning components and students’ experiences and knowledge. The teachers could benefit from CDAT components regarding how to make connections between students’ current learning status with their targeted status.

Overall Conclusions

This dissertation takes the position that a teacher’s role is evidently critical in students’ learning science. However, what the teacher’s role is and how it impacts
students’ understanding has been debated for the last several decades. The fundamental principle of inquiry-based science teaching and learning is that the opportunities for whole-class and small-group discourse must be included in the process of scientific inquiry (Hackling et al., 2010). How can classroom discourse be a part of the inquiry based learning process? In any type of classroom discourse, teachers can play a critical role for the students’ learning even in student-student discussions or student group presentations. Teachers’ talk should not dominate the classroom discourse, but it should support students’ exploration of ideas, comparison of alternative explanations, testing and evaluation of ideas, and reasoning with ideas and evidence (Hackling et al., 2010; Lemke, 1998).

In this study, the conceptual framework and the analytical tool (CDAT) for science classroom discourse has been developed with classroom observation data from the CCMS study. The framework combines the idea of scientific reasoning and formative feedback to be applied for the science classroom discourse. The formative feedback theory provides the ways of questioning and feedback, while scientific reasoning suggests what to deliver on teachers’ feedback. Aligning appropriate questioning, feedback, and discourse moves to phases of scientific inquiry may develop a discourse that maximizes learning outcomes (Hackling et al., 2010; Lemke, 1998).

The CDAT analysis produces various visualized and quantified data from science classroom discourse. With the resulting information, several representative values were developed such as LOD, #RC, and MRC as well as two models for a discursive and scientific classroom dialogue, the LOD model and the #RC model. The informative
values and exploratory models suggest several implications of the CDAT and suggestions with the results from this study.

Appropriate combinations of questioning, feedback, reasoning components, and discourse’s moves are required to enhance students’ engagement in classroom discourse and possibly improve students’ scientific understanding and reasoning skills. Depending on a class type and purpose, specific feedback and reasoning components could be more productive. Using more RCs and providing students with more opportunities to talk is hypothesized to be better for students’ learning. When an instructional purpose is to review classroom activities and ideas generated during activities and to elicit scientific explanations, a transition from RCs of OD and PD to SK or EX by utilizing proper subsidiary and feedback questions can be appropriate for the purposes.

Effective teachers often facilitate a productive and scientific classroom discourse with their students by drawing out and visualizing the students’ ideas throughout the conversation, moving towards the moment of students’ understanding at the end of a discursive dialogue. The core ideas of CDAT analysis is illustrating how science teachers support their students’ constructive understanding by providing diagnostic and formative information about their classroom discourse with regards to scientific reasoning and inquiry.

Interventions that support teachers to effectively use discursive dialogue with CDAT analysis could be demonstrated to have significant and positive effects on the learning processes and outcomes, and on students’ cognitive development in future studies. Further research and professional development opportunities for secondary
science teachers and pre-service teachers can be applied to develop the skills and understandings that will generate productive and scientific classroom discourse and enhance students’ scientific literacy and reasoning skills.
References


Appendix A: Coding Book
Coding Book (Ver 1.5)

for Science Classroom Discourse Analysis Tool (CDAT)

SoonChun Lee

July 18, 2012
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Introduction & Overview

A science classroom discourse consists of teacher talk and students’ talk in which the teacher talk could be questions and feedback and students’ talk could be also questions and responses to the teacher question. In a science classroom, a teacher question is usually to assess students’ understanding, but it could be also to scaffold students’ learning as a type of feedback to respond to students’ answers. Teachers’ feedback can have various purposes and methods.

Combining two aspects, formative feedback as a method of delivering teachers’ questions and feedback and scientific reasoning to lead students’ thinking, the idea of an analytical tool to assess how teachers’ feedback leads classroom discourse to be scientific was incubated. The CDAT was created by combining teachers’ feedback levels, teachers’ and students’ utterances of questions and answers, and reasoning components. Table 1 below is a Classroom Discourse Analysis Table (CDAT) with an example Dialogue 1.

Dialogue 1
T: So what is speed? Q1 You all should probably be able to tell me that without even having to look at your book because you speed to school every day, right? Q1.1
SS: Nope. No. R1.1
T: You don’t? Don’t you all ride the school bus? Q1.2
SS: Yes. No. R1.2
T: Is speed involved in getting to school? Q1.3
S: Yeah. R1.3
T: Yeah, what is speed? Q1.4
SS: Movement. R1.4
T: It’s movement, F1.4 ok, and what two things do we use to calculate speed? Q1.5
SS: Distance traveling over time. R1.5
T: Distance traveled over… f2Q1.6
SS: Time. R1.6

CDAT 1

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge</th>
<th>Everyday Reasoning (EDR)</th>
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<td>Feedback</td>
<td></td>
<td>1.1 Elaborative</td>
<td>1.3, 1.4, 1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2 Corrective</td>
<td>1.4, 1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.3 Evaluative</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Discourse Episodes, Dialogues, and Utterances**

As shown in Table 2, a class consists of classroom activities and classroom talk, and on the other hand, classroom talk consists of classroom discourse and other talk, while classroom discourse includes several classroom episodes that consist of several dialogues and a dialogue consists of students’ and a teacher’s utterances. Table 2 shows what components of the classes are used for the CDAT analysis. Among these components, each teacher’s or students’ utterance was analyzed as a unit of coding and a dialogue between a teacher and students was coded as unit of episode. A CDAT is for a dialogue or a few dialogues and each utterance in a dialogue was coded in an appropriate cell in the CDAT.

**Table 2 Components of a Class**

<table>
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<tr>
<th>Classroom Activities</th>
<th>Whole Classroom Talk (Between a teacher and students)</th>
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<td>Lab, Problem Solving, Group Work, Discussion, Demonstration, ...</td>
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</table>

**Coding Units: Discourse Episodes**

As shown Table 2 above, the components of classroom discourse are episodes, dialogues, and utterances. A discourse episode is determined as a teacher-students conversation about scientific content between other classroom activities such as experiments or problem solving seatwork. Therefore, an episode can have several dialogues with various topics and a dialogue would have a few or many utterances. A CDAT is for coding one dialogue or several dialogues depending on the dialogue’s length. In the case of coding several dialogues in a CDAT, each dialogue must have different one digit number.

**Coding Units: Discursive Dialogues**

Gee et al. (2004) also defined a series of tums of talk that all relate to the same topic or theme as an episode unit. A dialogue between a teacher and students is defined as a unit of episode that consists of consecutive utterances. When a dialogue starts, the first question will be assigned a new number and in the same dialogue, all added utterances have decimal notation such as 1.1, 1.2, 1.3, and etc.
A new question is defined as a question that requires a different answer from the previous one. When a question requires part of the previous question, it is considered as a subsidiary question that still belongs to the same dialogue coded with a decimal notation. However, the exactly same question can often be regarded as a new question: if it is questioning to other students’ after giving feedback or finishing a cycle of dialog. In the same dialogue, a question before providing a feedback, questioning to confirm or provide think again/back can be considered as a subsidiary question.

One dialogue starts with a new question and it ends when another dialogue starts with another new question. Therefore, the definition and criteria of a new question is critical, but it is sometimes very sophisticated. A new question is distinguished by noting that the answers to this question are uniquely different from the previous one. However, when the answers of a new question in a dialogue are responses to the answer of the first question, the new question still belongs to the same dialogue. Another difficult part in the coding scheme is identifying a subsidiary question that is also related to determining a new question to determine a dialogue. A subsidiary question is defined as a question that has a part answer of the former question. For example, the question “It deals with speed, but what else?” has a partial answer of the previous question, which is classified as a subsidiary question. However, in the dialogue 5.1 below, Q3 is related to the previous Q2, but it does not have partial or the same answers so Q3 is classified as a new question with a new number “3”.

Dialogue 2

T: for velocity to change are what two things? Q2
S: Velocity. R2
T: What two things make up velocity? Q2.1
S: Speed. R2.1
T: Speed or… fQ2.2
S: Direction. R2.2
T: Direction. F2.2 So can you tell me the two places on this graph where he changed velocity? Q3
S: In the middle. R3

Coding Units: Utterances

In their book introducing Critical Discourse Analysis (CDA), Gee et al. (2004) defined “Utterance” as a unit of speech that corresponds to any uninterrupted stretch of speaking by one or more people. Gee added a description of utterances as a unit of discourse analysis:
Within a dialogical approach to language, the utterance (rather than the phoneme, morpheme, word, phrase, or sentence) is the basic element of language in use. From the point of view of analyzing individual contributions to dialogue, the change of speaking subjects or turn taking is a natural unit of analysis (p. 87).

Likewise, Hicks (1993-6) maintained “Whereas sentences were defined by their formal structure, utterances were defined by changes of speaking subjects. Hence, the units of analysis for studies of language became a unit of social communication (p. 51).” In this dissertation study, the unit of coding for the discourse analysis is an utterance of a teacher, a student, or students. An utterance begins and ends at a turn-change when the speaker changes. Basically, an utterance is a communication unit such as a question, an answer, a feedback, or a prompt which could be a sentence, a phrase, or sometimes just a word. When teacher or student talk includes several utterances, each utterance was coded separately.

A Dialogue with Subsidiary Questions and Feedback Questions

Classroom discourse includes several discourse episodes and one discourse episode is determined from when it starts after a classroom activity until it ends when a new classroom activity is initiated. An episode consists of several dialogues between a teacher and students. According to Lemke (1998), Triadic Dialogue is comprised of the teacher’s question, student’s answer and teacher’s evaluation also known as an IRE discourse pattern. Therefore the conversations between a teacher and students can be considered as dialogues although more than one student may participate in that conversation. In the classroom discourse, the dialogues are not always typical IRE patterns; many variations of the patterns occur. For example,

Dialogue 3
T: Then I get in my car and go to the store; E9 what’s going to happen to the line? Q9.1
SS: It’s going to go up. R9.1
T: It’s going to start getting steeper again. F9.1 Will it go as steep as it did the first leg of the trip? Q9.2
SS: No. R9.2
T: No. F9.2 So I have leg one steep; E9.3 leg two I’m flat, no more distance. E9.4 Leg three I’m going to start going up again. E9.5 Here’s what I want you to think about. P10

Dialogue 3 can be considered as extended IRE pattern with the set of a question (Q9.2), a response (R9.2), and a feedback (F9.2) with the explanations (E9.3, 9.4, and 9.5). Some different types of dialogues cannot be defined based on the IRE pattern. Teachers sometimes use many explanations before or after a question and use various
questions even after a question. Although this dialogue has two Question-Response-Evaluation (QRE) patterns, set 9.1 and 9.2, the dialogue includes a portion of teacher’s explanation after the second question and the two patterns are linked by Q9.2 making a longer dialogue. I named the types of questions such as Q9.2 subsidiary questions. In the Dialogue 4 below, the teacher extends the dialogue with feedback responding to students’ answers.

Dialogue 4

T: If I’m on the freeway, what’s my slope going to look like? Q7
S: Down. R7 It’s going to go up in speed. R7.1
T: I’m going to go up in speed. Why? fQ7.2
S: Because [inaudible]. R7.2
T: So what does the slope look like if I gain speed? fQ7.3
S: Steeper. R7.3
T: Pardon? fQ7.4
S: It’s steeper. R7.4
T: It’s steeper. Thank you, Adam. F7.4 What’s going to happen when I get to the grocery store and I stop? Q8

In the dialogue above, the feedback-question fQ7.2 and fQ7.3, makes it longer until there is a new question Q8 that starts a new dialogue. A dialogue is defined as teachers’ and students’ consecutive utterances as they construct understanding about the question/content. Therefore, in a dialogue, the role of subsidiary questions and feedback-questions is critical to form the dialogue’s length, variety, and purpose that depend on a teacher’s instructional method to lead students’ thinking productively to reach the moment of understanding.
1. Teacher Feedback Levels

Table 4 Feature of Feedback Levels

<table>
<thead>
<tr>
<th>Level</th>
<th>Main Aspects</th>
<th>Focus</th>
<th>Feedback Content type</th>
<th>Delivery Style</th>
<th>Effects on Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Evaluative, Normative</td>
<td>Student</td>
<td>Grade, Praise, Evaluation, Comparisons with others</td>
<td>General comments, No reason, attention is &quot;self&quot;, too long, vague, difficult, or interruptive students' prompts</td>
<td>No effects</td>
</tr>
<tr>
<td>2</td>
<td>Corrective, Verification</td>
<td>Task</td>
<td>Correction, Right answer, Direct hint, Try again, Location of mistakes, Addressing information</td>
<td>Short, clear, fast in written and spoken</td>
<td>Sometimes effective</td>
</tr>
<tr>
<td>3</td>
<td>Elaborative, Facilitative</td>
<td>Task</td>
<td>Hint/Cue for the direction, Specific error or misconceptions (what and why)</td>
<td>No correct answers, manageable units for students, considering students’ level, specific and clear goal orientation, flexible time management</td>
<td>Effective almost always</td>
</tr>
</tbody>
</table>

* Synthesized from the studies of Hattie & Timperley, 2007; Kluger & DeNesi, 1998; Shute, 2008

1.1 Level 1: Evaluative/Normative

**Overview:** From the review by Shute (2008), Kluger & DeNesi (1998), and Hattie (2007), the evaluative feedback that provides too general or vague information including praise or evaluation could be ranked level 1, which has no effect or negative effects on students’ learning and performance. Level 1 feedback also may include wrong information, confusing information, tangential phrases that distract students’ attention, or no responses. As the name evaluative feedback implies, the basic understanding about this is evaluating students themselves or students’ responses without any specific information and/or no reason. Through the analyses of teachers’ feedback, the boundary of level 1 feedback has been expanded to include vague feedback, comparison with others, wrong information, and direct but irrelevant hints.

**Coding Strategy:** Without any specific reason, praising, evaluating, comparing with other students will be coded at level 1. Wrong, vague, confusing information or tangential mentions that distract students’ attention could be also ranked level 1.

If a feedback points out some errors in a students’ answer, then it could be level 2 feedback even if it is so simple and short. The feedback with wrong information should be lower than level 1 as well as a direct hint such as “the word starts with an E” and giving answer without additional explanation. When a teacher read the students’ responses without any comments, all the utterances belong to level 1 feedback.

**Key words:** Grade, praise, evaluation, comparison with others, general comments, no reason, attention to students not to task.
Language Evidence & Examples:

Dialogue 5
T: Hello, Cory, is it greater or less? Q1.17
S: Less. R1.17
T: Huh? Exactly, you’re not listening. F1.17

Dialogue 6
T: Well it is related to work. F1 Work and? fQ1.1
S: Amps! R1.1
T: It starts with an “E.” F1.1
S: Electricity! R1.2

Dialogue 7
T: How do you use an ammeter? Q1
S: Oh, I know! R1
T: No actually you do not. F1

Notes
1. If the teacher provides high levels feedback but the information is not scientifically correct, which level the feedback could be?

2. When a teacher’s feedback does not include information of correct or not but the praise implies the students’ answer is correct, and then it belongs to level 2.
1-2 Level 2: Verification/Corrective

Overview: Shute (2008) classified formative feedback into two categories: verification and elaboration. Verification is the simple information of whether an answer is correct, the most common way involves simply stating “correct” or “incorrect,” with sometimes correct answers as level 2 feedback. The basic description of Level 2 feedback is that it provides corrective information without specific information about the reason why. The key difference from Level 1 feedback is providing the simple information of whether an answer is correct; the most common way involves simply stating “correct” or “incorrect.” Questioning can also be one type of feedback, named feedback question. I classified two types of feedback-questions: one is confirming questions to explicit students’ answers that are Level 2 feedback; the other is elaborative questions to deepen students’ thinking that is level 3 feedback. The Dialogue 5 and 6 shows the examples of L2 and L3 feedback questions: Level 2 is fQ7.6 and fQ3.3 and Level 3 is fQ7.7 and fQ7.8.

Coding Strategy: Teachers provide the information correctness such as “right” or “wrong”, rephrasing students’ answers, or having them think/try again by repeating incomplete answer. Any follow-up question could be level 3 feedback but only when it leads students to think more with direction, suggestion, explanation but without providing the right answer. If a feedback points out some errors in a students’ answer, then it could be level 2 feedback even it is so simple and short.

Key Words: Correction, right answer, try/think again, short, clear, fast in written and spoken.

Language Evidence & Examples:

Dialogue 8
T: So what’s the actual formula for speed? Q6
S: Average of distance over time. R6
T: Right. Your total distance over total time.

Dialogue 9
T: what tool do I use to try to measure how I’m going at one particular second? Q3.2
S: Odometer. R3.2
T: What’s that called? fQ3.3

Notes & Questions: 1. What if the corrective information is wrong?
1.3 Level 3: Elaborative/Facilitative

Overview: Level 3 feedback is the highest level of elaboration responding to students’ answers and questions that could provide relevant cues to guide the learner toward a correct answer to address the topic, response, particular error, provide worked examples, or guidance (Black & Wiliam, 1998; Hattie & Timperley, 2007; Kluger & DeNisi, 1998; Kulhavy et al., 1983; Shute, 2008). Almost all research studies on teacher feedback maintain that this level feedback has a strong positive effect on students’ performance or learning (Black & Wiliam, 1998; Hattie & Timperley, 2007; Kluger & DeNisi, 1996; Shute, 2008). The following dialogue 7 includes two level 3 feedback F8.7 and F9.1 since they provide the reason and directions to think rather providing information of right or wrong.

Coding Strategy: Uptake questions associated with the previous one could be level 3 feedback. If there is specific information about why the answer is correct or is not. Providing the opportunities to think again with additional information without providing the exact answer could be this level.

Key Words: Location of mistakes, addressing information, hint/cue for the direction not right answer, specific error or misconceptions (what & why), no correct answers, manageable units for students, considering students’ level, specific and clear, goal orientation, flexible time management

Language Evidence & Examples:

Dialogue 10
T: But when I’m not moving, what’s the word you used, Adam? Q8.7
S: Flat. R8.7
T: The line’s going to be flat because I’m not gaining any more distance. F8.7
I’m just – the time is still passing. E8.8 So my distance line is going to stay the same, but time continues. E8 9 Then I get in my car and go to the store; E9 what’s going to happen to the line? Q9.1
SS: It’s going to go up. R9.1
T: It’s going to start getting steeper again. F9.1

Notes
1. If feedback is provided as form of question, should it belong to Question or Feedback? feedback Question = fQ
Subsidiary Question vs. Feedback Question

Overview: Distinguishing between subsidiary questions and feedback questions requires careful analysis. In the 9 below, Q1.3 is a new question and Q1.4 is a subsidiary question not a feedback question while Q1.5 could be both a subsidiary and a feedback question. However some feedback questions are not subsidiary questions when asking about students' thinking such as, “Why is it right?” or “Ok, so you're talking about the slant of the line?” Both types of questions have large positive impacts on the pattern of dialogue by creating longer dialogue on one topic that helps students with their journey to the moment of understanding.

Subsidiary and feedback questions also have different aspects in their purposes and authentic roles. First, the purpose of feedback questions is to strengthen the desire of the students to create different insights while participating in the provided activities that require them to think more/again. However, a feedback question in this level does not have to trigger high level of cognitive thinking, but rather, might be just a simple question such as ‘why’, ‘how’, or ‘how about …’, etc. Second, a feedback question is more authentic for students to learn by themselves. With feedback questions, the dialogue can be extended in productive directions to scientific understanding. On the other hand, the purpose of subsidiary questions is to lead students' thinking to a certain point on the way to the moment of understanding. Using subsidiary questions requires teachers to be prepared and ready in anticipating the probable answers from the students. Subsidiary questions may be very effective and efficient in helping students' understanding. But on the part of the students, these questions can hinder their own thinking process since the teacher points out what to think.

Coding Strategy: As shown in Figure 1 below, a question can be clearly classified as a subsidiary question or a feedback question. For example, if a teacher asks students' thinking like “How do you think like that?” or “Explain more?” then they are clearly feedback questions. However, if a teacher asks about a specific point in the content such as “What is the second aspect of velocity?” then the utterance is a clearly a subsidiary question. However, a question can also be both a subsidiary and feedback question. If a teacher asks “Why do you think speed is different from velocity?” since it asks about both students’ ideas and specific aspects of the content, this question can be either or both.

![Figure 1. Subsidiary Question vs. Feedback Question](image-url)
Therefore, differentiating between these two questions is not always clear or even necessary since both have the same goal that is to lead students in understanding the question and answer. Furthermore, when feedback questions and subsidiary question are combined, the questions might become more specific and productive for students’ scientific understanding. Following are two example dialogues that include subsidiary questions, feedback questions, and sub-feedback questions.

**Language Evidence & Examples:**

**Dialogue 11**

T: So if we went back to slope, what’s our saying for slope? \textit{Q1.3 (new)} It’s what over what? \textit{Q1.4 (subsidary question)}

S: Rise over run. \textit{R1.4}

T: Rise over run and you would not... \textit{F1.4} What’s on our rise this time? \textit{fQ1.5 (subsidary-feedback question)}

S: Velocity. \textit{R1.5}

T: Velocity. \textit{F1.5} What’s on our run? \textit{Q1.6 (subsidary question)}

SS: Seconds? \textit{R1.6 / Time. R1.7} (Teacher Daisy 2008-04-08P5)

**Dialogue 12**

T: Are you going to go the same speed as you drive to school? \textit{Q2 (new)} What do you do between? \textit{Q2.1(sub)}

SS: Stop. Go. \textit{R2.1}

T: Stop, at a stop light, and then what do you do? \textit{fQ2.2(sub-feedback)}

S: Go. \textit{R2.2}

T: You go, and as you start leaving the stop light what do you do? \textit{fQ2.3 (sub-feedback)} As you leave you get a little what? \textit{Q2.4 (sub)}

S: Faster. \textit{R2.4}
2. Scientific Reasoning (SR)

The common components of scientific inquiry are observations/data, patterns, and models/theories to be dealt with when scientists do science as inquiry. In addition, there are five common phases in scientific inquiry as methods or process as of inquiry: questioning, hypothesizing, designing, testing and analyzing, and building theories or predicting phenomena. Those phases are cognitive devices to make connections between the inquiry components and thinking and doing science. For example, questioning is a scientific thinking activity with observations/data, hypothesizing is a thinking activity with data, patterns, and models, and testing is scientific activity with data, pattern, and models as well. Those inquiry components and phases are controlled and organized by scientific reasoning as a way of scientific thinking. Therefore, learning scientific reasoning is not just practicing a way of thinking but practicing how to deal with those inquiry components and phases in both doing and thinking science. Furthermore, the practices will improve students’ scientific understanding and literacy. In science classrooms, scientific inquiry activities are ways of practicing scientific reasoning. However, without follow up scientific discourse, producing scientific understanding and literacy could be limited (Hackling et al., 2010; Lemke, 1998).

Although we cannot measure how well students conceptually understand and develop reasoning skills, the ways teachers’ use feedback or prompts can be examined to assess whether it is scientifically consistent or not (Boyatzis, 1998; Hardy et al., 2010; Windschitl et al., 2008). The conceptual model (Figure 3.3) suggests the effective pathways of transforming students’ reasoning methods, in which the distances between two components in everyday reasoning (ER) or scientific reasoning (SR) represent the relative difficulties of the transformation. This model will help science teachers to figure out where students’ ideas currently belong, what the goal status is, and how to move to the next step.

![Figure 2 Bridging EDR and SR by TF revised from Anderson, 2007, p. 12 and 18](image-url)
2.1. Scientific Knowledge (SK)

Overview: Scientific Knowledge (SK) is defined as simple scientific concepts and definitions that teachers want their students to learn. Although scientific knowledge can be considered the same as scientific literacy and is the ultimate goal for students in science education, scientific literacy should be accomplished in the process of inquiry activities and discourse. However, SK still has a big role when students build new understanding by connecting their previous experiences to new experiences and evaluating whether to accept the new learning and integrate it into their scientific understanding. Furthermore, some learning objectives often include basic scientific concepts and definitions that students should learn.

Coding Strategy: For the coding, the utterances of SK are defined as scientific concepts, definitions, equations, or formulas. However, if the utterances have connections to observation/data (OD), they were coded in the OD cell in CDAT.

Language Evidence & Examples:

Dialogue 13

T: Okay. One last question. What is joules? Jimmy said joules. What is joules?
Ray: Q1
S: Work. R.1
T: Well it is related to work. F1 Work and?/Q1.1
S: Amps! R.1.1
T: It starts with an “E.”/Q1.2
S: Electricity! R.1.2

CDAT 11

<table>
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<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Experience</th>
<th>Scientific Knowledge (SK)</th>
<th>Scientific Reasoning (SR)</th>
<th>Observation/Data (OD)</th>
<th>Future from Data (FD)</th>
<th>Models/Theories (MT)</th>
<th>N/A</th>
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<tr>
<td>Explanation/Examples</td>
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<td>L1 Connective</td>
<td>L1 Evaluative</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Q1.2</td>
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</tbody>
</table>
2.2 Observation/Data (OD)

Overview: Observation and Data (OD) is defined as descriptions of natural phenomena or quantified values used as examples or derived from the class inquiry activities. Through the analysis, I found that it is sometimes difficult to distinguish students’ experiences (EX) from ODs since the example observations can start from every day experiences.

Coding Strategy: If teachers provide an example with certain data such as weight, speed, distance, color, or description and ask something related to the data such as distance, weight, color, changes in observation, then it could be into this category. OD can produce either SK or PD: when a teacher explains a concept using the observation data, then the utterances belong to SK but when a teacher draws a generalization, comparison, or contrast, that is an inference from the OD then it’s a PD. In the Dialogue 14 below, teacher Ann asked first about students’ experiences (Q2), but then she asked the students to think about what they did in that experience and had them explain the situation. So, I classified Q2.1, fQ2.2, fQ2.3, and Q2.4 as questions about OD.

Language Evidence & Examples:

Dialogue 14

T: Are you going to go the same speed as you drive to school? Q2 What do you do between? Q2.1
SS: Stop. Go. R2.1
T: Stop, at a stop light, and then what do you do? fQ2.2
S: Go. R2.2
T: You go, and as you start leaving the stop light what do you do? fQ2.3 As you leave you get a little what? Q2.4
S: Faster. R2.4
T: You go a little faster. F2.4 So the average speed is just talking about all your speeds averaged together. E2.5

CDAT 12

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Relevance</th>
<th>Scientific Reasoning (SR)</th>
<th>Observation/Patterns from Data (PD)</th>
<th>Models/ Theories (MT)</th>
<th>N/A</th>
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<td>Question/Prop</td>
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<td>2.1.2.3.24</td>
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<tr>
<td>Feedback</td>
<td>L1 Evaluative</td>
<td>L2 Corrective</td>
<td>L1 Evaluative</td>
<td></td>
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</tr>
</tbody>
</table>

Notes & Questions:

(1) Data/observations in example situations can be coded in this category? Yes, if teachers mention about quantities or descriptions.
2.3 Patterns from Data (PD)

Overview: Patterns from Data (PD) include reasoning that involves generalization, comparison, contrasts, relationships, diagrams, graphs, table, computation, categorization, and differentiation. When teachers' or students' utterances are not just about OD but also include manipulating the observation/data, they belong to PD in CDAT. Therefore, dealing with tables, graphs, or diagrams are in this category, but if the discourse is just about a graph's characteristics, definitions, or how to make it without any data then the discourse is categorized as SK. Problem solving with given data is also classified in this category, but if the discourse is only about formulas or how to solve the problem mathematically without any data, then the utterances are coded in the SK category. In the Dialogue 13, teacher Cory provides an observation/data from what students did first, E6 and E6.1, and then asked how it appears on the graph as a line, Q6.2 and Q6.3. Those questions are not asking about if it is faster or slower, but are asking students to make a connection to the movement and the line. That is the main reason why they belong to the PD category. However, if a teacher asks “What’s our saying for slope? It’s what over what?” the questions belong to SK.

Coding Strategy: If teachers ask about relationship, connection, or table and graph from an observation or data. When doing an inquiry lesson with some experiments, if the teacher can ask question about graph, table, connection, or relationship, then it also could be into this code level.

Language Evidence & Examples:

Dialogue 15

T: Lance, we started here walking. F6 The CBR was our reference point or our starting point. E6.1 When we walked from the CBR out across the line, what direction did the line on the graph make? Q6.2 Did it go up or down? Q6.3
S: Up. R6.3
T: Up, so it was a positive, so it was true. F6.3 What did we call it when we come back towards the reference point and the line goes down? Q7 What’s the opposite of positive, Rashid? Q7.1
S: Negative. R7.1
T: Negative. F7.1

CDAT 15

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (ER)</th>
<th>Scientific Reasoning (SR)</th>
<th>Observation Data (OD)</th>
<th>Patterns from Data (PD)</th>
<th>Models/Theory (MT)</th>
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<tr>
<td>Student Response/Question (R)</td>
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<td></td>
<td></td>
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</table>
3. Everyday Reasoning (EDR)

Overview: Students’ explanations for natural phenomena are usually based on everyday experiences which are usually not compatible with scientific models and need to be revised to align with scientifically valid ideas (Duschl, 2008). Anderson (2007) called everyday pattern finding practical reasoning which children approach to make sense of the world from their experiences and current knowledge.

3-1 Everyday Experience (EX)

Overview: Questioning or investigating students’ experiences (EX) is really important for students’ learning and is emphasized by many educators especially those holding a constructivists’ view of teaching and learning.

Coding Strategy: All kinds of questions, examples, explanations, and feedback about students’ experience (EX) belong to EX in CDAT table. The utterances as experiences (EX) coded are not limited to direct students’ personal experiences but included any kinds of everyday life experiences such as teachers’, from movies, or histories.

Language evidence & Examples:

Dialogue 16

T: Time and distance, ok? F3.1 So really, it’s just a ratio of how far have you gone in a certain amount of time. E3.2 And you all deal with speed all the time. E3.3 You all are in baseball, you all are in track, you measure your speed. E3.4 When you drive to school everyday, roadtrips, when you’re on the Interstate or in your neighborhood. E3.5

CDAT 16

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Knowledge</th>
<th>Scientific Reasoning (SR)</th>
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<td>Question/Prompt</td>
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<td>L1Corrective</td>
<td>L1Evaluative</td>
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Notes & Questions:
3.2 Naïve Explanation (NE), Model/Theories (MT), and Naïve Knowledge (NK)

Overview: NE is about students’ misconceptions or naïve explanation with their own theories from their experiences. NE can be originated from students’ belief, others’ authorities, common sense, force-dynamic reasoning, or confidence from experiences. Scientists explain/predict natural phenomena with MT, but students’ explanations could be the result of informal reasoning with their own theories. If researchers investigate students’ written discourse such as an assignment, an essay test, or online communication with CDAT, they may find some cases of NE and MT as well as students’ small group discussions or students’ presentations in project based learning.

Naïve Knowledge (NK) has two aspects. First, naïve knowledge is a form of common belief, legitimated by commonsensical opinions and not reliant on ‘certainty’ in any scientific sense (Gardiner, 2000). I was planning to code whenever I found students’ or even teachers’ misconceptions or naïve knowledge. However, I realized that evaluating their knowledge is beyond the scope of this study. Therefore, I chose the second aspect about teachers’ discourse with regards to the misconception or students’ misunderstanding. However, this category almost never appeared in the coded discourse except one case in Teacher Cory’s discourse (see Dialogue 17).

Language evidence & Examples:

Dialogue 17

T: The slope. Whew! We know that; good. F3 This is a misconception that many of you – because I kept giving these on your mid summative exams – E3.1 you kept getting the different lines when we looked at the boats – remember the boat races? E3.2 And you saw three different lines. E3.3 A lot of you told me one of the boats was faster because the line was longer. E3.4 Is that true? Q3.5

S: No. R3.5

T: No. F3.5 We can extrapolate and make that line as long as we want on a graph. E3.6 If we want to know the average speed we’re going to look for… Q3.7

S: The slope. R3.7

CDAT 17

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<tr>
<th>Discourse Type</th>
<th>Knowledge Type</th>
<th>Everyday Reasoning (EDR)</th>
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<td>L1/Evaluative</td>
<td>L1/Evaluative</td>
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</table>
4. Off Topic Talk (N/A)

Overview: Off topic talk coded as N/A are the utterances that are not relevant to the topic. These utterances were mostly talk to manage or discipline students' behaviors during the discourse dialogues. Teachers' prompt that is to get students attention or pushing students to do could also be in N/A. In an episode, the same question to force/encourage students to answer could belong to N/A but the same question to other students and a related question not responding to students' answers can be a subsidiary question coded with a decimal notation. If teachers' talk and students' talk are not related to the lesson such as about the technology, students' attitudes, or small talk, they will be coded N/A.

Coding Strategy: In the example Dialogue 15 below, the teacher focused on only the observations on the projector screen. However, if off topic utterances are disregarded marked with small numbers like F1.28, p1.29, or R1.31, the dialogues 1 and 2 turned out to be very simple QRE patterns with only a single reasoning component of OD as shown in the Table CDAT 15.

Language evidence & Examples:

Dialogue 18

T1: One. Well if you're frozen, F1.28 I guess you'd better make it [inaudible].
Zero. P1.29 Ok, so did most of them make it to a crest? P1.30
S: Nope. R1.30

T1: Here's a crest; here's a crest, that's good. F1.30 Here's a crest. Are there any other crests? Q1.31

S: There's so many people on that one... R1.31

T1: I think we have some people frozen; F1.31 we've got a few people in a trough instead of a crest. P1.32
S: I went to a trough; R1.33 I didn't realize... R1.34

T1: Ok, let's try it again. P2.1 Let me individualize your cursors this time. P2.1
Let's try it this time real quick. P2.2 We're going to move to a trough. Q2.3

cR2 SS: Good, transfers. R2.4 Some people are still... R2.5 Yellow, I got an orange triangle. Oh, yeah. R2.6

T1: Go to a trough. P2.7
S: Wait, where are we going? R2.7

T1: To a trough; any trough you like. P2.7
SS: Stop it. [class laughs] R2.8 I was making fun of you the other day. R2.9 I'm sorry, I'm sorry. R2.10

T1: Trough; you want to go to a trough. P2.11 Ok, you need to find a trough. P2.12
SS: What's a trough? R2.13 The lower point. R2.14 It's the negative crest; R2.15 look at the arrow. R2.16 There we go. Is that right? R2.17

T1: Yeah. Ok. I think they talk about [inaudible] troughs. F2.17

CDAT 15

<table>
<thead>
<tr>
<th>Discourse Type</th>
<th>Knowledge Reasoning</th>
<th>Everyday Reasoning (EDR)</th>
<th>Scientific Reasoning (SR)</th>
<th>N/A</th>
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<tr>
<td>Explanation/Examples</td>
<td>NS (NE)</td>
<td>NS (EX)</td>
<td>NS (NK)</td>
<td>NS (SK)</td>
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<td>Feedback</td>
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<td>1.3 Elaborative</td>
<td>1.3 Elaborative</td>
<td>1.3 Elaborative</td>
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Appendix B: IRB Approval
July 26, 2011

Protocol Number: 2005B0114
Protocol Title: CLASSROOM CONNECTIVITY IN PROMOTING MATHEMATICS AND SCIENCE ACHIEVEMENT, Karea Irving. Douglas Owens, School of Teaching & Learning.
Request to amend the protocol dated 07/12/11—Add use of video data for SoonChun Lee’s dissertation

Type of Review: Amendment—Expedited
Approval Date: July 25, 2011
IRB Staff Contact: Jacob R. Stoddard
Phone: 614-292-6526
Email: stoddard.13@osu.edu

Dear Dr. Irving,

The Behavioral and Social Sciences IRB APPROVED the above referenced research.

Note that if applicable, informed consent (and HIPAA research authorization) must be obtained from subjects or their legally authorized representatives and documented prior to research involvement. The IRB-approved consent form and process must be used. Changes in the research (e.g., recruitment procedures, advertisements, enrollment numbers, etc.) or informed consent process must be approved by the IRB before they are implemented (except where necessary to eliminate apparent immediate hazards to subjects).

It is the responsibility of all investigators and research staff to promptly report to the IRB any serious, unexpected and related adverse events and potential unanticipated problems involving risks to subjects or others.

This approval is issued under The Ohio State University’s OHRP Federalwide Assurance #00000373.

All forms and procedures can be found on the ORRP website – www.orrp.osu.edu. Please feel free to contact the IRB staff contact listed above with any questions or concerns.

Shari R. Speer, PhD, Chair
Behavioral and Social Sciences Institutional Review Board