ENHANCING KNOWLEDGE BUILDING DISCOURSE IN EARLY PRIMARY EDUCATION: EFFECTS OF FORMATIVE FEEDBACK

by

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Abstract

This research focuses on a Knowledge Building pedagogical approach and investigates ways to boost students' competencies in knowledge creation processes, specifically their ability to contribute productively to high-level explanation-seeking discourse. This study uses a design-based methodology to explore how pedagogical and technological innovations can enhance students' ways of contributing to knowledge building discourse, and examines whether expanding students' contribution repertoire helps them to advance community knowledge in general. Gains associated with a Knowledge Building approach for secondary and post-secondary students are widely documented. This research adds to this body of literature by showing how a Knowledge Building approach can be productively engaged at the early primary level. This work also contributes to studies exploring automated feedback and assessment tools that can help boost student capacities for building new knowledge.

The research was conducted in three main phases. The first phase mapped the ways that students from Grades 1-6 (n = 102) contribute to their naturally occurring Knowledge Building discourse in order to provide baseline data for subsequent design experiments. The following two phases corresponded to two design iterations that involved work in Grade 2 science and that tested different types of formative feedback. Design Cycle 1 (n = 42) focused on testing supports to boost low-frequency contribution types. Design Cycle II (n = 43) aimed to reproduce and improve results from the first iteration. In both design cycles, pedagogical supports included whole-class metadiscourse sessions, while technological supports consisted of contribution and content-oriented feedback tools that offered students a meta-perspective on their own discourse, including Word Clouds (Cycle 1), Concept Clouds (Cycle 1-2), visualizations produced by the Metadiscourse Tool (Cycle 1-2), and verbal scaffolds (Cycle 1-2).

Analyses of data revealed that these supports helped students to significantly increase their engagement with targeted contribution types, diversify their general contribution repertoire, and advance collective knowledge beyond that attained by their peers in prior years. This research provides empirical evidence that Knowledge Building inquiry can be effectively engaged at the primary level, and offers usable artifacts tested and shown to be conducive for helping young students raise the level of their Knowledge Building discourse.

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CHAPTER ONE: INTRODUCTION

1.1 Chapter Overview

This research is focused on the design, development, and implementation of educational innovations to boost young students' competencies in knowledge creation processes, specifically their ability to contribute productively to high-level explanation-seeking discourse. The broader goal is to develop educational means to increase capacity for sustained creative work with ideas. The studies described in this thesis explore how pedagogical and technological innovations can expand students' ways of contributing to group dialogue, and investigate whether enhancing students' contribution repertoire helps them concurrently to advance community knowledge in general. This chapter begins with a discussion of the motivation for the research, followed by a description of the study's major objectives and its central research questions. It then briefly describes the pedagogical approach used for this study. The chapter concludes with an overview of the organization of the thesis.

1.2 Motivation for the Study

The ability to produce new knowledge can be described as a capacity for "productive work that advances the frontiers of knowledge as these are perceived by [a] community" (Bereiter & Scardamalia, 2003). Increasingly, societal capacity for innovation and the creation of new knowledge is required to address the sorts of complex problems that characterize the 21st century, such as accelerating climate change, widespread financial downturns, and global political unrest (David & Foray, 2003; Homer-Dixon, 2000; 2006). For individuals living and working in the current "knowledge age" (Drucker, 1994, 1968; Bell, 1973; Toffler, 1990), being able to generate and work creatively with ideas is critical for productive engagement in society. For instance, recent research has shown a significant re-organization of the modern workforce as society shifts from a production-based to knowledge-based economy, with abstract tasks and knowledge-oriented work surmounting manual activities and physical labour (Autor, Levy, & Munane, 2003). As the new millennium progresses, the competencies that are critical to success and productivity in contemporary workplaces and that are increasingly valued by industry align closely with features of knowledge-creating organizations such as scientific think tanks, design studios, or innovative companies (Scardamalia, Bransford, Kozma, & Quellmalz, 2010), and include high-level communication skills as well as the ability to generate novel solutions to complex problems (e.g. Dickerson & Green, 2004). Additionally, more and more workplace settings are becoming technology-rich spaces that require a workforce that can deal with ill-defined problems, operate productively in multi-disciplinary teams, and work across distributed networks (Griffin, Care, McGraw, 2012).

If nations wish to leverage new technologies to their full capacity, however, investments in both promising innovations as well as in developing a workforce with the capacity to use them must be a priority (Becker, 1993). Expertise in dealing with emerging technologies requires a 21st century citizenry that is equally adept at problem solving, critical thinking, and the ability to communicate productively across broad networks (Gillmore, 1998). On a global scale, the scope and magnitude of social, economic and environmental problems is incongruous with society's capacity to confront and tackle them. For instance, Thomas Homer-Dixon (2000) conceptualizes the discrepancy between emerging global needs and society's capacity to confront them as an *ingenuity gap*, that is, "the critical gap between our need for ideas to solve complex problems and our actual supply of those ideas." From this perspective, limitations for solving particular problems do not arise from a lack of any material resource, but rather from the extent of a society's capacity to innovate and generate novel solutions to these problems. Bereiter and

Scardamalia (2006) underscore this point, asserting that what has remained generally unacknowledged but that “lies at the very heart of the knowledge economy…is the ability to work creatively with knowledge *per se*” (p. 700). With the prosperity and well-being of nations bound to the innovative capacity of global citizens, arming the next generation workforce with the ability to create new knowledge and generate novel solutions to complex problems represents a pressing social, political and economic imperative (Rotherham & Willingham, 2009; Rotherham, 2008).

A citizenry that can work productively and creatively with knowledge is one that is capable of processing abstract concepts, collaborating across broad networks, and generating innovative solutions to multidimensional problems (Karmarkar & Apte, 2007). In order to reform education to meet the needs of the new millenium, a number of emerging educational programs directly target so-called “21st century skills” (e.g. Binkley, Erstad, Herman, Raizen, Ripley, & Rumble, 2009; Johnson, 2009; Trilling & Fadel, 2009), which speak to competencies in the following areas: creativity and innovation, communication, collaboration, information and media literacy, critical thinking and problem solving, ICT literacy, life and career skills, metacognition, and cultural competence—all in addition to core content knowledge (e.g. Trilling & Fadel, 2009). Examples of such programs include the “Partnership for 21st Century Skills” (P21), which represents a joint venture between the American business and education sectors; Canadians for 21st Century Learning and Innovation (C21), a collaborative organization made up of educational associations as well as knowledge-based businesses that advocate for the acceleration of Canadian educational systems to adopt 21st century skills frameworks; and the Assessment and Teaching of 21st century skills (ATCS), which is an international venture dedicated to implementing and assessing 21st century skills, as well as identifying technological and pedagogical barriers that frustrate educational reform to these ends.

A major challenge that arises concurrently with the development of 21st century learning programs is the need to create effective assessments that can be used to evaluate the complex processes involved in high-level knowledge work (Gipps, 2002; Shepard, 2000). Indeed, as Resnick and Resnick (1992) affirm, changing what students learn necessitates changing the ways students are assessed. This point is underscored by the 'US National Science Education Standards', which asserts that assessment and learning are two sides of the same coin (National Research Council, 1996). At the turn of the century, literature on assessment practices focused largely on such things as providing feedback on student work (e.g., tests and projects) and in-class questioning. New assessments that target specific 21st century outcomes need to involve meaningful indicators for complex processes that address both "hard" and "soft" skills; make learning goals and objectives explicit; outline specific methods for monitoring progress; provide clear data and methods for tracking individual progress as well as important element of group interaction; and offer feedback that is easily accessible to both students and teachers (Scardamalia, Bransford, Kozma, & Quellmalz, 2012). Moreover, in order for new assessments to contribute to the "systemic" change necessary in educational reform, they need to reveal evidence of participation and collaboration as well as knowledge gains and learning outcomes that map onto new competencies (Bereiter, 2002; Chan & van Aalst, 2004).

Emerging technologies are vital elements of innovative educational environments and can be used to inform and enhance the design of new assessments that are aligned with changing conceptions of teaching and learning. Indeed, in schools, as well as in industry, processes of knowledge creation are becoming inextricably bound up with technology (Karmarkar & Apte, 2007). However, simply introducing technology into classrooms does not guarantee beneficial outcomes. In fact, despite the growth of educational innovations, there remain significant shortcomings between the use of technology and education (Collins & Halverson, 2009). For instance, technological "fads" can be enthusiastically met and quickly accepted, but once integrated into classroom routine can become utilized in traditional ways (e.g. a Smartboard becomes a high-tech blackboard) or used only rarely as a side-project or novelty (Maddux & Cummings, 2004). Furthermore, for students whose only access to technology is in the classroom, possessing ICT skills without gaining the sorts of higher-order competencies necessary for working creatively with knowledge also limits the efficacy of these new technologies and their capacity to help prepare students to productively participate in a knowledge society (Scardamalia, 2003). For these reasons, researchers and educators warn that technical innovations for education must be research-driven and encompass systemic reform while emerging from actual practices and enacting sound pedagogical principles (Laferrière, 2001; Law, 2006; Raizen, 1997).

1.2.1 Knowledge Building

Knowledge Building provides an educational approach that is uniquely suited to research for developing 21st century competencies and corresponding assessments. Knowledge Building can be described as "*the production and continual improvement of ideas of value to a community*" (Scardamalia & Bereiter, 2003, p. 1370). In both its theoretical and technological dimensions, Knowledge Building is synonymous with knowledge creation. In educational literature, Knowledge Building tends to be equated to learning (p. 2), however, Bereiter and Scardamalia (1996) draw a definitive distinction between the two concepts: For instance, 'knowledge building' supports innovation and the creation of new knowledge, while 'learning', on the other hand, is more concerned with the 'transmission' or 'acculturation' of a culture's achievements to new members. Knowledge Building pedagogy is dedicated to immersing students in a culture of knowledge creation and places the advancement of community knowledge as the explicit and shared goal (Scardamalia & Bereiter, 2003). Because new knowledge is advanced in large part through the discourse of knowledge creating communities, a key aspect of Knowledge Building is the commitment to engaging students in sustained explanation-seeking or "progressive discourse" (Bereiter, 1994), which is sustained by a commitment to continually advance shared knowledge. Knowledge Building discourse is enhanced by Knowledge Forum (KF), which is an online environment specifically designed to support high-level knowledge work (Scardamalia, 2004). Knowledge Forum supports "intentional" or "expert" learners, and provides a collective knowledge space for students to contribute and improve their own ideas (Scardamalia & Bereiter, 2010). Both online and offline, Knowledge Building pedagogy focuses on creative work with ideas, with shared discourse as its driving force.

Immersing students in a knowledge creating culture provides an opportunity to have students engage with critical 21st competencies such as technology literacy, collaboration, critical thinking, and problem solving in authentic inquiry practice, with the objective of creating new knowledge serving as the collective goal. Available evidence suggests that Knowledge Building can produce both gains in core content knowledge, basic skills in literacy and numeracy, as well as a host of what are termed "21st century skills." For instance, research shows that students working in media-rich Knowledge Building environments demonstrate gains in media, visual and ICT literacies (Gan, Scardamalia, Hong & Zhang, 2007; Sun, Zhang & Scardamalia, 2008). Studies have also found benefits of engaging in Knowledge Building discourse associated with deeper conceptual understanding (Chan & van Aalst, 2003; Hakkarainen, 2003; Hewitt, 2002; Lee, Chan, & van Aalst, 2006; Lipponen, 2000; Oshima, Scardamalia, & Bereiter, 1996); achievements in domain knowledge; (Kangas, Seitmamaa-Hakkarainen, Hakkarainen, 2007; Pelletier, Reeve, & Halewood, 2006; Zhang, Scardamalia, Lamon, Messina & Reeve, 2007); scientific reasoning and inquiry (e.g., Bereiter, Scardamalia, Cassells, & Hewitt, 1997; Resendes & Chuy, 2010; Scardamalia; Bereiter & Lamon, 1994; Zhang, Scardamalia, Reeve & Messina, 2009); and, finally, higher levels of scientific literacy and superior scientific writing (Bereiter & Scardamalia, 2009; Chuy, Scardamalia & Bereiter, 2009).

The design of new assessments for supporting knowledge creating practices are vital in order to scale up a Knowledge Building approach in classrooms, and to make knowledge creating work within educational settings more widespread (van Aalst, Chan, Chan, Wan, Chan, Teplovs, 2010). Assessments that are deeply linked to the most important dimensions of Knowledge Building practice need to track and support both individual and collective aspects of knowledge advancement (cf. Lee, Chan, & van Aalst, 2006), as well as help students move beyond a "knowledge-sharing" towards a "knowledge creating" discourse (van Aalst, 2009).

Developing new assessments to boost sustained explanation-seeking discourse in Knowledge Forum represents a goal shared by a growing number of research programs (Burtis, 1998; Lee, Chan, & van Aalst, 2006; Teplovs, Donahue, Scardamalia, & Philip, 2007; Oshima, Oshima, & Matsuzawa, 2012; van Aalst, Chan, Chan, Wan, Chan, & Teplovs, 2010; Yang, van Aalst & Chan, 2012). These initiatives aim to enhance student discourse through the invention of new assessment technologies that are specifically geared towards supporting important dimensions of Knowledge Building, such as idea improvement, collaboration, and conceptual change. The research reported in this thesis shares this objective, and focuses on testing new assessments to boost the presence of diverse contributions to collaborative, explanation-seeking dialogue, which is another important indicator of productive Knowledge Building work (Matsuzawa, Oshima, Oshima, Niihara, & Sakai, 2011; Oshima et al., 2012; van Aalst et al., 2010). Creating and testing designs to support students' engagement in a diverse set of ways of contributing to explanation-seeking discourse represents an approach to creating new assessments for Knowledge Building that can be used to both evaluate and boost collaborative processes as well as deepen shared knowledge. Innovations of this type are necessary in order to more fully describe and assess student dialogue geared towards idea improvement, and to bootstrap important processes of knowledge creation.

1.3 Research Objectives

The research reported in this thesis seeks to contribute to the body of literature informing designs of new, scalable assessments to scaffold Knowledge Building practices, with a focus on supporting sustained explanation-seeking discourse. More specifically, the study reported here explores the kinds of contributions primary aged students can make that help move explanation-seeking dialogue forward, and tests designs oriented towards boosting students' ability to effectively contribute to collaborative knowledge creating discourse. As noted, gains associated with a Knowledge Building approach for secondary and post-secondary students are widely documented. The proposed study seeks to add to this body of literature by showing how a Knowledge Building approach can be productively applied to work of young students at the early primary level. This work also aims to contribute to studies exploring automated feedback and assessment tools compatible with or embedded in Knowledge Forum that can help boost student capacities for contributing effectively to explanation-seeking discourse.

1.3.1 Research Questions

(a) How do young students contribute to collaborative explanation-seeking discourse in their naturally occurring knowledge building work? Are there any valuable ways of contributing that are rare or absent from student discourse, and can thus serve as targets for design work?

(b) How can the design of new feedback tools help students expand their ways of contributing to explanation-seeking discourse?

(c) To what extent does expanding student contribution repertoire help them to advance community knowledge?

1.4 Organization of Thesis

This dissertation is organized into nine chapters. In Chapter 2, literature relevant to the research project is reviewed, with a focus on the theoretical and pedagogical underpinnings of Knowledge Building. In Chapter 3, the methodology used in the study is described. In this chapter I also discuss the participants, research setting and approach to data analysis, and provide a brief overview of the three study phases of the research, which include an initial exploratory study coupled with two iterative design cycles. In Chapter 4, I report the results of the preliminary study, which provides a description of the ways elementary school students across Grades 1-6 contribute to explanation-seeking dialogue in their naturally occurring discourse. This study provides benchmark data and guides design choices for subsequent phases of the project, which are reported in the next three chapters. In Chapter 5, I describe Design Cycle 1 of the research project. In this phase, we tested the extent to which pedagogical and technological supports could boost low-frequency contribution types, as indicated by the preliminary study, in the Knowledge Building discourse of Grade 2 students. In Chapter 6, I report secondary analyses of the data collected from Design Cycle 1 and describe gains in literacy—namely the growth of students' vocabulary knowledge—as a byproduct of work geared to enhance explanation-seeking discourse. Chapter 7 details Design Cycle II, which extends the work conducted in the first iteration. Based on lessons learned from Design Cycle 1, research in Design Cycle II seeks to both reproduce and improve results to show the impact of innovative assessments on students' capacity to contribute diversely to explanation-seeking discourse and to create new knowledge. Finally, Chapter 8 provides a general discussion on the research as a whole, and offers some conclusions and considerations for possible future work.

CHAPTER 2: LITERATURE REVIEW

2. 1 Chapter Overview

This chapter begins with an in-depth discussion of Knowledge Building theory, and details the major themes and pedagogical principles that underpin the approach. Next, the idea of discourse as a primary means for creating new knowledge is elaborated. I go on to detail critical components of explanation-seeking dialogue, including an exploration of important ways of contributing to collaborative Knowledge Building discourse. The discussion then shifts to discuss new technologies for supporting high-level discourse in computer-supported collaborative learning environments. I then elaborate on the promise of new assessments for boosting student capacity for engaging in Knowledge Building dialogue. The chapter concludes with a consideration of innovative formative assessments geared towards expanding student contribution repertoire, with the goal of helping students to enhance their explanation-seeking discourse and advance community knowledge.

2.2 Theoretical Foundations: Knowledge Building

Knowledge Building is a social constructivist pedagogical approach. Defined as one of the five foundational approaches to the learning sciences (Sawyer, 2006), Knowledge Building can be described as “the production and continual improvement of ideas of value to a community” (Scardamalia & Bereiter, 2003, p. 1370). Knowledge Building shares theoretical roots with a range of constructivist and socio-constructivist approaches, including inquiry-based models such as Problem-Based Learning (e.g. Barrows, 1985), Project-Based Learning (Blumenfeld, et. al, 1991; Hmelo-Silver& Barrows, 2008), Learning by Design (Holbrook & Kolodner, 2000), as well as “knowledge community” models such a Brown & Campione’s (1994) Fostering

Communities of Learners (FCL). As pedagogical approaches emerging from socio-constructivist traditions, these models possess common traits. For instance, Inquiry-Based Learning (IBL) models emphasize student-centered practice, as well as authentic problem solving and collaboration in the construction of knowledge (e.g. (de Jong and van Joolingen, 1998; Khun et al, 2000). Similarly, what Slotta has terms "knowledge communities" stress the importance of distributed expertise, and emphasize metacognitive aspects of learning, and strategies for sharing knowledge across groups (e.g. Brown and Campione, 1989; Slotta & Peters, 2008).

Knowledge Building shares a dedication to these themes in both its theoretical and pedagogical framework, but is distinct in its commitment to immerse students in sustained and emergent processes of knowledge creation from an early age (Bereiter & Scardamalia, 2003). Knowledge Building theory has developed from decades of cognitive research on intentional learning (Bereiter & Scardamalia, 1989) and on the processes of acquiring expertise (Bereiter & Scardamalia, 1993). As Bereiter and Scardamalia (2012) argue, all core domains share the goal of pursuing ever-deeper understanding and explanations of the world—a pursuit that can be understood as theory-building (p. 160). Conceiving the pursuit of understandings of the world as theory-building "is an especially productive way of regarding it if understanding is to be pursued by means of student-conducted inquiry" (Bereiter & Scardamalia, 2012, p. 161). In Knowledge Building, students are galvanized as a community and direct their efforts at building theories to explain problems of understanding that are identified and articulated by the community itself. Knowledge Building engages students in "deep constructivism" (Scardamalia & Bereiter, 2003) whereupon students take responsibility for advancing group knowledge. "Deep constructivism" refers to processes in which students are aware of the underlying principles of the tasks they conduct, as opposed to "shallow constructivism," in which teachers or another centralized authority possesses the ultimate means for advancing knowledge (Scardamalia & Bereiter, 2003).

Knowledge building pedagogy is designed to support the challenges of in-depth inquiry through its emphasis on community, collective responsibility for knowledge advancement, rigorous use of source material, and support for sustained, collaborative explanation-seeking dialogue.

2.2.1 Knowledge Building Principles

Scardamalia and Bereiter (2006a) outline six central themes that describe the priorities of Knowledge Building pedagogy and help to distinguish Knowledge Building from other socio-constructivist approaches such as those mentioned earlier. These themes encompass the twelve foundational principles of Knowledge Building (Scardamalia, 2002), and are elaborated below:

i) *Knowledge advancement as community rather than individual achievement:* Collaboration and social organization is central to knowledge creating endeavours (Bereiter, 2002; Engeström, 1987; Nanoko, 1994). Recognizing the importance of group interaction in the creation of knowledge challenges individualistically oriented conceptualizations of learning that are predominate in cognitive constructivism. Current approaches to learning emphasize issues like participation (Sfard, 1998), interactional meaning making (Stahl, 2006; 2010), and dialogic interaction (Wegerif, 2006). Learning activities that emphasize collaboration and the active co-construction of ideas can be more effective than even the most constructive individual learning tasks (Chi, 2009). A Knowledge Building perspective asserts that knowledge that is generated in the process of theory-building needs to be continually created, verified and advanced—ideas have a public life, accessible to every member in the community, with each having the opportunity to build on, critique, and in other ways advance community knowledge. Collaboration in Knowledge Building efforts can lead to individual learning gains (Chuy et al., 2011), however, achievements in knowledge advancements are shared by the group, and as such, are valued over individual accomplishments.

In order to ensure that the group succeeds in reaching shared goals, each student is encouraged to take up "*collective cognitive responsibility*" (see Scardamalia, 2002) for advancing knowledge. For example, just as a efficient legal team will take responsibility for understandings all aspects of a case and for staying on top of events as they occur, students take up collective cognitive responsibility for their knowledge building work by "tak[ing] responsibility for knowing what needs to be known and for insuring that others know what needs to be known"(Scardamalia, 2002, p. 2). Critical to the process of taking "collective cognitive responsibility" is for students to take on *epistemic agency* for charting the course of their own learning. It is common in other inquiry-centred models for problem-solving processes to be enacted using a "guided discovery" (Brown & Campione, 1994) or "scripted" (e.g. Kollar, Fischer, & Hesse, 2006; Dillenbourg & Jermann, 2007) approach, in which the main themes for inquiry are preselected by teachers or researchers, and incorporate pre-articulated questions and fixed end goals. With these approaches, and even in instances where free discussion is encouraged, a great of extent the talk is highly mediated by the teacher, who poses questions with predetermined answers (Corden, 2001; Nystrand, 1996). In contrast, from a Knowledge Building perspective, problem-solving is "any goal-directed activity in which the path to the goal is unknown and must be discovered or invented" (Scardamalia & Bereiter, 2010, p. 4). Throughout the problem-solving process in Knowledge Building, students take on responsibility for devising and carrying out key decision-making processes that will help them move closer to their knowledge creation goal. As Scardamalia and Bereiter (2007) argue, "What is distinctive [about Knowledge Building] is having student-designed questions, theories, and empirical work as the principal means by which knowledge is expected to advance in the classroom, with other means subordinate to it. It is in this sense that Knowledge Building students are engaged in real epistemic invention rather than only role-playing" (p. 16). Rather than bending knowledge construction efforts to predefined questions and fixed endpoints, Knowledge Building students initiate their inquiry around *real ideas and authentic problems*, which are questions or problems that students themselves "[genuinely] wonder about" (Scardamalia & Bereiter, 1992). Rallying inquiry around "real ideas and authentic problems" calls for students to participate in the process of initiating and building up a framework or context for the problems to be investigated that can help formulate a path for their inquiry before students take on the task of utilizing the "tools" of any one discipline to formulate explanations (Bereiter & Scardamalia, 2012). Once students begin theorizing work on a particular authentic problem, they must then continually engage in processes that can help them to advance their own learning, including contribution generously to shared discourse, assessing the state of community knowledge at any given time, and planning next steps.

Moreover, ensuring that every group member takes "collective cognitive responsibility" and engages in these and all other aspects of community knowledge advancement is reinforced in the principles of *democratizing knowledge* as well as *symmetrical knowledge advancement*. With respect to the former, this principle describes the commitment Knowledge Building communities have to ensure that each and every participant has access to community knowledge and can act as legitimate contributors to the shared discourse. As Scardamalia (2002) describes, in a thriving Knowledge Building community, "the diversity and divisional differences represented in any organization do not lead to separations along knowledge have/have-not or innovator/non-innovator lines. All are empowered to engage in knowledge innovation" (p. 11). Thus, Knowledge Building communities not only work together to solve problems but operate within a knowledge creating culture that affords every member the opportunity to engage and benefit (Anderson, Holland & Palinscar, 1997). The concept of creating a democratic knowledge creating culture is bound up with the principle of *symmetrical knowledge advancement*, which is based on the notion that "to give knowledge is to get knowledge" (Scardamalia, 2002, p. 11). This principle emphasizes the importance of distributed expertise in advancing group knowledge, such that expert knowledge flows within and between communities and is available for every member at all times so that all members rise together. In order for such dynamic interaction to occur between students, and to ensure Knowledge Building ethos prospers in a community, the classroom culture must be one of psychological safety, so that students feel safe to take risks, "revealing ignorance, voicing half-baked notions, [and] giving and receiving criticism" (Scardamalia, 2002, p. 9). Indeed, a number of studies suggest that successful learning communities ought to nurture feelings of security, acceptance and inclusion (Alexopoulou & Driver, 1996; Bateman, Goldman, Newbrough & Bransford, 1998), and that feelings of community and social cohesion can be enhanced by encouraging open dialogue between student members (Barab, Dodge, Thomas, Jackson, & Tuzun, 2007; Hale & City, 2002; Weber, Maher, Powell & Lee, 2008). Thus, the theme of *knowledge advancement as community rather than individual achievement,* and the principles that speak to it, help to describe characteristics of a knowledge creating culture as well as the ways in which such a culture can be nourished and sustained, since maintaining a healthy shared culture is vital to the success of a Knowledge Building community (Bielacyzc, 2006).

ii) *Knowledge advancement as idea improvement rather than acceptance or rejection of ideas:* The notion of *improvable ideas* can be described as a central organizing principle around which Knowledge Building theory and pedagogy is built. In Knowledge Building practice, ideas are considered real things—artifacts that can be continually built upon and advanced (Scardamalia & Bereiter, 2006a). The notion of treating ideas as "real things" stems from the work of Karl Popper, namely, his theory of the three worlds of knowledge. According to Popper, alongside the realms of material reality (World 1) and mental states (World 2) is the realm of conceptual artifacts, such as ideas (World 3). These conceptual artifacts, or ideas, exist “out in the world” rather than wholly in the minds of individuals, and thus are accessible and available for continual development, understanding and criticism. Thus, the work of advancing the state of conceptual artifacts or ideas is achieved through collaborative knowledge work geared to towards their improvement (Bereiter, 2002). In Knowledge Building, participants work continuously to improve the quality, coherence, and utility of ideas with the goal of creating “epistemic artifacts”—tools that represent the frontiers of the community’s knowledge and which themselves can be built upon and expanded (Sterelny, 2005). “Epistemic artifacts” can be fully conceptual and take the form of theories, models, narratives, diagrams, and so on (Bereiter, 2002). As Scardamalia and Bereiter (2003) assert, the epistemic value of such artifacts is their “feedforward effect”, the notion that knowledge can be continually advanced. From this perspective, epistemic artifacts students produce “are to be judged not so much by their conformity to accepted knowledge as by their value as tools enabling further growth” (Scardamalia & Bereiter, 2006a).

In addition, encouraging all students to be active participants in the effort to improve ideas (as described in the preceding theme) fuels the presence of *idea diversity* in shared discourse. As Scardamalia (2002) asserts, “To understand an idea is to understand the ideas that surround it, including those that stand in contrast to it. Idea diversity creates a rich environment for ideas to evolve into new and more refined forms” (p. 9). Productive Knowledge Building work calls for students to take on a ‘web-like’ view of ideas and become accustomed to exploring complementary and contrasting ideas and concepts, as well as the ways that an assortment of ideas might relate and connect to one another. Indeed, forming relationships and connections between seemingly disparate objects is a highly creative act (Mendelsohn, 1976; Mendick, 1962; Sternberg, 1999). For instance, in his exploration of creative genius, Simonton

(1999) discusses the importance of "ideational variants" in the process of problem solving. As Simonton describes, the greater the idea diversity, the greater the chances for new and creative associations to be drawn between these ideas; moreover, the stronger the lateral ties in a community, the greater the chances the group will produce a wide range of ideas. The principle of idea diversity supports the concept of 'combinatory play" with ideas — something that Einstein called the "essential feature of productive thought" (as qtd in. Brewster, 1955, p. 43). Encouraging idea diversity helps to nurture divergent thinking, which entails the ability to generate many alternative solutions to a problem and which is essential to the ability to innovate (cf. Heilman, Nadeau, & Beversdorf, 2003).

iii) *Knowledge of in contrast to knowledge about:* The concepts of "knowledge of" and "knowledge about" can be used to represent different dimensions of expertise. The distinction is analogous to that which philosopher Gilbert Ryle (1949) made between "knowing that" and "knowing how". For instance, "knowing that" is largely tacit and exercised in the process of completing a task. "Knowing how" deals with an understanding of principles, concepts and ideas. "Knowing how" corresponds to "knowledge of" and entails what Hatano and Inagaki (1986) call "adaptive expertise." This type of expertise is characterized by the following attributes: efficiency, flexibility, innovative thinking, metacognition, and deep understanding. In contrast, "knowledge about" can be reached satisfactorily through "routine expertise." This type of expertise entails the ability to perform a task efficiently—for example, taking a test, reciting facts that have been memorized, or creating a poster-project about a certain topic—but without any real knowledge of its underlying principles.

It has been argued that traditional school curricula, being "a mile wide and an inch deep" (Schmidt, McKnight, & Raizen, 1997, p. 62), are more conducive to teaching "knowledge about" than "knowledge of" the subjects covered. Indeed, the sheer volume of content and the speed with which curricula must be covered over the course of school year has been criticized as posing barriers to deep learning and discouraging "deep dives" into the subject matter (Trilling & Fadel, 2012). As opposed to "covering" a broad range of content at a surface level, Knowledge Building engages students in sustained theorizing work around authentic problems, with the goal of achieving ever-deeper understandings. Indeed, a theory-building approach by nature requires students to develop "knowledge of" the problems and concepts they are investigating. For instance, as Chi and Ohlsson (2005) describe, "theories are 'deep representations' in the sense of having well-articulated centre-periphery structures" (p. 373). In other words, a theory is built and organized around a core set of concepts—typically abstract and foundational ideas—that provide the framework for the rest of its components. Students working to create and advance theories are engaging deeply with relevant subject matter and with corresponding critical concepts—developing "knowledge of" the problem spaces they are dealing with—in addition to cultivating skills related to communicating these theories (writing narratives, researching secondary sources, articulating ideas, etc.)—that help illustrate their "knowledge about."

The Knowledge Building principle that speaks most directly to encouraging "knowledge of" is that of *rise-above*. This principle speaks to a community's shared effort to continually advance community knowledge to new frontiers. *Rise-above,* or the idea of continually advancing beyond current levels of knowledge, requires community dedication to formulating higher and higher-level conceptualizations and to developing deep knowledge about a particular problem. Commitment to this principle means students need to develop and deepen their capacities to work with complex information and, by so doing, to continually surpass their own accomplishments (Scardamalia, 2002).

Indeed, deepening students' own conceptions requires handing over high-level work to the students themselves. Moreover, in their Knowledge Building efforts, students are encouraged to integrate ideas, events, questions, information or any object of discourse they might encounter in their daily life into the group dialogue as legitimate artifacts for group scrutiny and discussion. In this sense, students are encouraged to engage in pervasive Knowledge Building such that inquiry is not confined to particular times or topics but "pervades mental life" (Scardamalia, 2002). Encouraging students to engage in their Knowledge Building work as an active and ongoing process that benefits from input they might encounter and ideas they might have at any point in their daily life is important for helping students to see their classroom-based work as more than procedural or routine tasks but as relevant to the world outside of the classroom.

iv) *Discourse as collaborative problem solving rather than argumentation:* At the core of knowledge creating processes is community engagement in *progressive discourse* (Bereiter, 1994). Progressive discourse can be used synonymously with "Knowledge Building" or "explanation-seeking" discourse, each of which refers to collaborative dialogue that focuses on the continual refinement and improvement of ideas. Explanation-seeking discourse advances through a community's continued efforts to deal with puzzling facts, and through shared commitments to advancing the frontiers of group knowledge (Bereiter, Scardamalia, Cassels, & Hewitt, 1997). These commitments extend beyond the individual to encompass the entire community, and include the following: a commitment to progress—this entails the devotion to continual improvement of ideas; empirical testability—the willingness to have questions or propositions subject to validation and verification; openness —the effort to seek mutual understanding and to be open to challenges; and last, expanding the basis for discussion—the dedication to expanding networks of accepted facts and ideas that can be built upon by the group (Bereiter, 1994, 2002).

Furthermore, the commitment to knowledge creation helps to distinguish explanation-seeking dialogue from other forms of formal or academic dialogue that are often predominate in the classroom, namely argumentation or debate. While both types of formal dialogue can be distinguished from casual conversation in that they are goal-oriented (Walton, 1998), the nature of their discursive goals are fundamentally different. For example, argumentation maintains a focus on persuasion and on establishing the truth-value of a statement or assumption rather than on creating new knowledge, which is the objective of explanation-seeking discourse. As such, argumentation retains a supplemental role in Knowledge Building endeavours (Scardamalia & Bereiter, 2010).

Knowledge Building discourse and argumentation are analogous to what Bereiter and Scardamalia (2003, 2006b) call "design mode" and "belief mode" discourse. "Design mode" discourse favours the generation of new knowledge, whereas "belief-mode" discourse is concerned with establishing what one believes or ought to believe. Both types of discourse play important roles in different contexts. For instance, "belief-mode" discourse is reflected in knowledge artifacts such scientific publications that take on a persuasive tone, and as such is important for students to master (Woodruff & Meyer, 1997); however, the dialogue that actually goes on during knowledge building work is fundamentally different, and aligns with "design-mode" thinking, which is much more conducive and relevant to the learning process (Dunbar, 1997; Coleman, Brown, & Rivkin, 1997).

According to Bereiter and Scardamalia (2003), "schooling almost exclusively emphasizes one of these modes, whereas knowledge work in the real world mainly emphasizes the other" (p. 56). In contrast to other inquiry-based learning models, Knowledge Building pedagogy immerses students in sustained "design-mode" discourse in the interest of helping students develop capacities to create new knowledge. While explanation-seeking or "design-mode" discourse can ebb into argumentation or "belief-mode" dialogue at certain points and can, at times, represent a useful and mutually beneficial exercise for the group, prolonged engagement in discourse of this type can undermine knowledge creation efforts and impede momentum towards improving ideas. As Scardamalia and Bereiter (2010) explain, "often in knowledge creating dialogue it is not necessary and it is frequently impossible to establish the exact fact of a matter. The issue is whether the available information is good enough for its purpose" (p. 6). As the driving force of knowledge creation, *discourse as collaborative problem solving rather than argumentation* provides the backbone of a knowledge building community, and serves as a medium for developing students' abilities to engage in important Knowledge Building processes. As a focus for the research reported in this thesis, further elaboration on the nature of explanation-seeking discourse is provided in Section 2.3 of the current chapter.

v) *Constructive use of authoritative information:* Knowledge Building teachers aim to initiate collaborative problem solving by engaging students in generation of their theories and questions about phenomena to be explored—their authentic questions and ideas. Students then share responsibility for contributing and improving their ideas as members of a knowledge creating community. Concurrently, students are obliged to integrate empirical observation and established knowledge into their discourse in order to help them advance the limits of their own understanding, making *constructive use of authoritative information* and sources throughout the inquiry processes as needed. In Knowledge Building, students are encouraged to engage with sources not simply as primary carriers of information that they then memorize or absorb, but as tools which they use to validate, inform, corroborate and enhance their own original ideas and questions in the process of building theories and explanations. Students need to identify where knowledge gaps exist and seek valid sources of information that can help fill these gaps, building theories that increase the explanatory coherence of their community's ideas and explanations. This process of using authoritative information constructively does not mean injecting isolated facts into the discussion or reiterating information gleaned from textbooks or educational websites, but calls for a continual process of both inductive and deductive reasoning. For example, students need to develop abilities to "fit" evidence into an emerging explanation, which is an inductive act, but also need to learn how to decide exactly what evidence fits the necessary criteria for a particular explanation, which is a deductive one (Gaddis, 2002). Indeed, continual movement and co-ordination between theoretical conjectures and factual information is required for theory improvement (Chuy et al., 2010). Having a sense of the important facts that surround a problem space but also discovering how they fit together as a whole is necessary for deep understanding (Willingham, 2008). In the spirit of pervasive knowledge building, facts and information that students acquire from all aspects of life—whether from school resources, first-hand experiences, or other sources—has value if they serve to contribute usefully to Knowledge Building efforts of the community (Scardamalia & Bereiter, 2006a).

vi) *Knowledge as Emergent:* The dedication to support *emergent knowledge* represents one of the most significant differences between Knowledge Building and other inquiry-oriented pedagogical models. Supporting *emergent knowledge* requires a decentralized pedagogical framework, or what Mitch Resnick calls an "ecological learning environment" (Resnick, 1996, 2003). According to Resnick, ecological learning environments possess two major characteristics: First of all, they are responsive to local conditions—that is, decisions are communal, and are based on ground-level dynamics that are not preset or centrally dictated; Second, they are adaptive to changing environmental conditions—strategies for what happens next change according to situational needs or circumstances, there are no scripts or predetermined solutions. As emergent and decentralized systems, knowledge creating organizations can be described as "ecological learning environments"—communities that are bound together by the shared objective to create new knowledge. These entities are not centrally controlled but are comprised of various component parts and characterized by numerous channels through which knowledge flows, and from which new knowledge is generated, validated, and continually advanced. Such an entity is kept in motion through the continued interactions of its distributed parts (Seely-Brown, 2000).

The notion of a "learning ecology" (Barron, 2004) as it pertains to education places emphasis on the interacting elements within a particular learning environment, including "the kinds of learning activities, the material and social resources for learning, the roles that learners take on, the knowledge distributed within social networks, and the practices for exchanging information" (Sawyer, 2006, p. 28). Ecological environments do not program learning experiences directly but create rich environments in which ideas can grow (van Aalst, 2009, p. 58). Concepts from social network analysis are also useful here to highlight how the importance of a vibrant, interconnected community is to Knowledge Building practice. For instance, from a social network analysis perspective, "social capital" arises out of the interactions of actors in a network, and can be explained as "benefits that exist only because a network of interacting actors exists, and as a resource embedded in and constituted by the social network" (Haythornthwaite, 2008, p. 153). Complementary to these ideas are the notions of "learning networks" and "learning capital." As Haythornthwaite (2008) describes, "a learning network is a network that "holds learning beyond the individual, [it is] a network endowed with 'learning capital,' whether that is knowledge held across the network or the practices of knowledge generation that the network sustains" (p. 154). These ideas help illuminate the theoretical underpinnings of Knowledge Building, namely its focus on maintaining a dynamic Knowledge Building culture where every single member is an active participant, as well as its emphasis on the process of emergent co-construction of new knowledge. At the core of the theoretical principles that underlie both Knowledge Building theory and pedagogy is the dedication to promoting conditions that enable a classroom community to function as an ecological learning network.

The last principle to be mentioned, that of *embedded, concurrent and transformative assessment,* speaks directly to the imperative of Knowledge Building to sustain a community built around the principles of emergence and decentralization and offers a guideline for pedagogical and technological supports to sustain a self-organizing community. For instance, *embedded, concurrent and transformative assessments* are assessments that are seamlessly integrated into the everyday activities of a Knowledge Building community, are understood and undertaken by the group itself, are oriented towards helping all members monitor progress and move towards shared goals, and are also designed to ensure that students not only achieve objects but outdo expectations and standards (Scardamalia & Bereiter, 2010). The sorts of information that can feed into such assessments, such as that produced by social network analysis, for example, can offer rich visualizations and feedback that can be used in situ by teachers and students themselves in a just-in-time manner, or also by researchers wishing to exploring the group level interactions of a particular community to inform designs for meaningful learning environments. In all cases, designs for assessments to support knowledge creation are driven by the commitment to starting students on a developmental trajectory that stretches from the inherent curiousity of children to the "disciplined creativity" characteristic of experts and competent knowledge creators (Scardamalia & Bereiter, 2003). As a critical element in the development of new Knowledge Building environments, possibilities for assessments for knowledge creating work are elaborated in the section below (see Section 2.5.3).

2.3 Discourse as the Medium for Knowledge Creation

From a Knowledge Building perspective, knowledge cannot simply be retained within the minds of individual members, but must exist "out in the world" (Bereiter, 2002, p. 5) as conceptual artifacts, which are human constructions that can be continually improved (p. 52). Furthermore, knowledge that is shared by a particular community "only exists in the discourse of that community, and the progress of knowledge just is the progress of knowledge-building discourse" (Scardamalia & Bereiter, 2006a, p. 102). These ideas represent a critical shift from a "mind-as-container" metaphor advanced by folk theories of learning, towards an understanding of knowledge as existing within and through the discursive practices of a given community. A growing body of educational research focuses on discourse as the primary medium through which knowledge is engendered. For instance, Wegerif (2006) promotes the engagement of dialogue "as an end in itself" (p. 144), and asserts that "dialogue is itself the primary thinking skill upon which all others are derivative" (p. 151). Drawing off the work of M.M. Bakhtin, Koschmann (1999) proposes that dialogic theory offers a new framework for re-conceptualizing learning in CSCL contexts. Additionally, recent social-constructivist studies exploring knowledge construction and the acquisition of expertise emphasize the central role of dialogue in these processes (Gee, 1991; Michaels & O'Connor, 1990; Seixas, 1993). Numerous other studies show that an emphasis on dialogue plays a vital role in a host of learning processes, including increasing students' abilities to test their own ideas, synthesize the ideas of others, and build deep understanding (Corden, 2001; Nystrand, 1996; Reznitskaya, Anderson & Kuo, 2007; Weber, Maher, Powell & Lee, 2008), and can also help boost student motivation, collaborative skills, and the ability to problem solve (Dyson, 2004; Matsumara, Slater & Crosson, 2008; Nystrand, 1996). Moreover, "non-traditional" forms of classroom dialogue (Cazden, 2001) (e.g. forms that do not follow an initiate-response-follow up [IRE] structure) but that allow for fluid and emergent discussion between students have also been shown to be more effective for boosting student engagement and participation than more traditional forms (Baird, Fensham, Gunstone & White, 1991; Lemke, 1990; Wood, 1992).

The educational benefits of immersing students in collaborative discourse are widely documented, however, discourse that can help students collaboratively improve ideas features unique attributes. So, what kind of discourse is best suited to help students create new knowledge? I turn to a more in-depth exploration of the nature of explanation-seeking discourse to address this question.

2.3.1 Structural model of Knowledge Building discourse

Progress has been made in recent literature conceptualizing the nature of explanation-seeking discourse (Scardamalia & Bereiter, 2006a; van Aalst, 2006, 2009). Bereiter and Scardamalia (2010) add to this research by offering a structural model that identifies the core elements of discourse oriented towards knowledge creation. In this model, these core elements can be conceived of as a set of critical dialogue "moves" that reside either on or off of a "problem solution path" (Conklin, 2005). The model includes the following discursive "moves": i) problem definition and analysis; ii) the generation of new ideas; iii) "promisingness" evaluations; and iv) next steps, which could include a return to any previously mentioned moves or to empirical research. Taken together, these elements represent the "main path of actions leading to a knowledge creation goal" (Bereiter & Scardamalia, 2010, p. 4). Corresponding to these discourse moves are activities that take place off the main path but can still figure as critical elements of successful discourse. These include: i) metadiscourse; ii) comparisons iii) belief mode discourse; and iv) principled procedural knowledge building (see Figure 1) which purports that knowledge has an application beyond that of the immediate problem (Bereiter & Scardamalia, 2010, p. 6). In both educational and professional contexts, collaborative knowledge creation is engendered by engagement in a variety of discourse "moves" that come together to carry the dialogue forward.

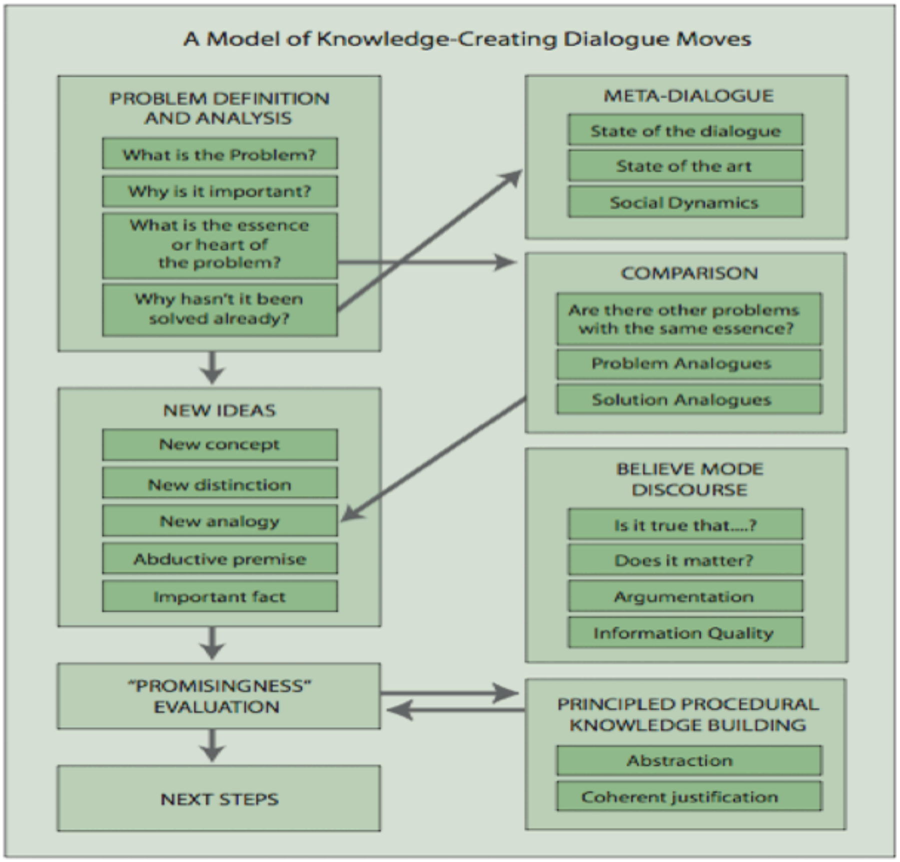

Figure 1. Basic sketch of a non-detailed structural model of knowledge-creating dialogue moves.

2.3.2. Explanatory Coherence

To help introduce and explain their structural model of Knowledge Building discourse, Scardamalia and Bereiter (2010) refer to the work of Chase & Simon (1973), who explored the characteristics of expertise in master chess players. These researchers found that expert chess players are not better at chess because they can consider a wider variety of moves than novices, but because they tend to consider only the *good moves* in accordance with the current state of play. In chess, "good moves" are moves that help to achieve the goal of capturing the opponent's queen. In Knowledge Building, "good moves" help advance students towards the goal of creating new knowledge and ever-deeper understandings of the world. Thus, in Knowledge

Building, as in chess, possessing an understanding of the most useful or promising "moves" that will help community members achieve a shared goal is essential. Indeed, as Bereiter and Scardamalia (2012) assert, "as junior theoreticians, students need to have some idea of what kind of theory they are building, and teachers need to be aware of this as well, in order to provide guidance" (p. 161). So, if expertise in chess includes the capacity to consider only the potential good moves in the ever-changing context of a game, how can students identify and decide on what constitutes good moves in an emergent, explanation-seeking discourse?

To this end, one could say that the "good moves" in explanation-seeking discourse are moves that help improve the coherency of a given explanation. Indeed, the pursuit of increasingly coherent explanations is at the heart of disciplinary thinking across domains and constitutes the primary attribute of any theory-building effort (Bereiter & Scardamalia, 2012). Paul Thagard's (1989, 2007) notion of "explanatory coherence" provides a framework for evaluating the quality of a given theory regardless of the domain. This concept, both theoretically defined and computationally modeled (Thagard, 2000, 2006), asserts that any theoretical proposition is subject to a set of core requirements, which include internal, logical coherence as well as coherence with empirical observations or acknowledged facts. In addition, according to this model, the level of predictive power and reliability a theory demonstrates helps to distinguish superior theories from inferior ones. Last, the most parsimonious explanation, or the explanation that can account for the greatest number of facts, can be understood as the "best" explanation at any particular moment throughout the theory-building process. In an educational context, a Knowledge Building community needs to have a sense that they are making progress, as well as be able to point to evidence that demonstrates their advancement. Creating a theory that accounts for the highest number of facts—and thus which exhibits the greatest explanatory coherence—provides an accessible framework for generating and assessing dialogue that encompasses high-level ideas and establishes a goal for raising the level of discourse across domains.

2.3.3. Contributor Roles

If advancing community knowledge is premised on improving the quality of shared discourse (Bereiter, 2010), then the question of how to boost students' capacities for "making good moves" in explanation-seeking discourse becomes central. In other words, what types of supports might help students to make the kinds of moves in explanation-seeking discourse that they need to make in order to create increasingly coherent explanations? Examining the nature of productive collaborative discourse in the classroom has been the focus of a number of studies in the field of the learning sciences, and offers a starting point for exploring this question. For example, cognitively-oriented approaches aimed at boosting levels of peer collaboration emphasize the importance of assigning a variety of distinct roles to individual students, each of which are designed to help community members contribute in productive ways like connecting ideas, making inferences or offering useful analogies (King 1994; Swing & Peterson 1982; Webb & Farivar 1994, Webb, Troper & Fall, 1995; Webb & Mastergeorge, 2003). Similarly, Leng, Lai, and Law (2008) discuss a taxonomy of contribution types to Knowledge Building discourse on the basis of levels of structural complexity. Perhaps the most well known of these cognitively-oriented studies is Edward de Bono's (1985) "six thinking hats." In this research de Bono singled out six strategies to help groups "think together" productively: i) considering facts and information; ii) taking on emotional reactions; iii) being logical, cautious and conservative; iv) seeking harmony and identifying positives; v) being creative, provocative and curious; and finally, vi) mediating or controlling the collaborative process. Similarly, socio-constructivist literature that explores the dynamics of sense-making groups in science classrooms has emphasized the importance of students' different roles in collaborative inquiry (Anderson 1994; Alexopoulou & Driver 1996; Anderson, Holland, & Palinscar, 1997; Richmond & Striley 1996). For example, in a study that focused on students' engagement in interactive, dialogic practices, Hogan (1999) identified 8 naturally occurring roles that are conducive to collective scientific reasoning, including roles such as promoter of reflection, contributor of content, creative model builder, and mediator of group interactions and ideas. Taken together, all of these studies highlight the impact of a dynamic interaction of various contributor roles and emphasize the presence of a range of contribution types as a prerequisite to productive collaborative classroom discourse.

Often, inquiry-based approaches adopt traditional co-operative methods and assign various contribution roles to students during group discussions (Kagan, 1992). However, in Knowledge Building, different contributor roles come together in an emergent self-organizing process (Resnick, 1996). Whereas ways that students contribute to the shared discourse will change over time, as different needs call for different moves (van Aalst et al., 2010), the diverse contributor roles remain bound together and carried forward by a shared commitment to advance collective knowledge. The section that follows discusses a variety of contribution types that are important to collaborative Knowledge Building work, and describes their role in discourse oriented towards creating new knowledge.

2.3.4 Ways of contributing to explanation-seeking discourse in science

In order to more deeply explore the particular contributor roles that are important to discourse oriented to knowledge creation, recent attempts have been made to chart the different ways of contributing that characterize the Knowledge Building discourse of students in practice. For instance, Chuy, Resendes, Tarchi, Chen, Scardamalia, & Bereiter (2011) present an empirically grounded list of ways of contributing to explanation seeking dialogue that describes a range of contribution types involved in the online discourse of elementary-aged students doing Knowledge Building work in science. It is important to note here that this scheme was the product of an exploratory study that was conducted in preparation for the research project out of which this thesis evolved, and in which I contributed as a co-researcher and co-author. I present a slightly adapted version of this inventory here in order to gain a more detailed look at the attributes of a range of contribution types that characterize explanation-seeking discourse geared towards scientific inquiry. In total, this list includes six main contribution types and 24 subtypes, each of which is described below:

(a) *Formulating thought-provoking questions:* The quality and type of question one poses influences the particular kind of dialogue that occurs in response (Skidmore, 2000, 2003; Wood, 1992). In science, asking thought-provoking questions that can frame productive inquiry constitutes a core competency (US National Science Education Standards (National Research Council, 1996). With respect to Knowledge Building work, questions are a force that drive the dialogue forward and help students to extend the lines of their thinking. Three kinds of questions that are important to knowledge building discourse and that can help increase explanatory coherence include: i) *Explanatory questions*—Questions of this type probe the "how" and "why" of various phenomena (Hakkarainen, 2003). These are particularly conducive to knowledge building dialogue, often serving to push the dialogue forward in new and promising directions; ii) *Factual questions*—Fact-seeking questions ask "what", "who" and "when" and typically call for isolated pieces of information. Factual questions are necessary components of explanation-seeking discourse, as the continual corroboration and integration of facts within a proposed theory is necessary to increase its coherence. Similarly, the higher number of facts to account for, the more challenging it will be to create a coherent frame that helps to explain the why and how behind them; iii) *Experimental design questions*—These questions ask: "How can we (empirically) prove or test something"? These types of questions have an important role in scientific inquiry, particularly in regard to processes of experimentation and testing hypotheses to carry research forward.

(b) *Theorizing*: Theorizing underscores scientific inquiry and the pursuit to construct new scientific knowledge (Carey & Smith, 1993). *Proposing an explanation*, for example, can be the first step in theory development. A half-baked idea can set off a dynamic discussion that leads to the refinement of that idea and can enable important knowledge advancements. Other important contributions to theorizing include: *supporting an explanation, improving an explanation, and seeking an alternative explanation*. Supporting existing theories with justifications can serve to add credibility and consensus to an explanation; it can also incite debate and "partisan motivation" around a particular idea, which can then be subject to further interrogation by the community (Hatano & Inagaki, 1992). Improving an explanation is the goal of explanation-seeking discourse, and can be arrived at in a number of ways: connecting disparate facts, introducing new evidence, elaborating an existing idea, or making a conceptual leap (Koestler, 1964). In the absence of any fruitful advances or insights, seeking an alternative explanation might help to get things "unstuck" and may provide a strong case for abandoning or rejecting a theory (Thagard, 2007). Indeed, the path to theory improvement typically includes both a convergence and a divergence of ideas, as approaching problems from various different perspectives can help get a range of sources integrated into the inquiry and can inspire creative ways to tackle the problem at hand (see Scardamalia, 2002).

iii) *Obtaining Information:* In science, information is gleaned from careful observation and controlled experimentation, which includes the identification of dependent and independent variables, use of appropriate materials, and the design of experimental conditions as vital elements required to test hypotheses and validate explanatory propositions (Gauch, 2003). In students' explanation-seeking dialogue, the presence of a wide range of facts, both from authoritative sources, empirical observations, and experiments, is needed to help students build upon their original ideas and increase the coherency of their theories. Moreover, when experimental designs fail or fall short of desired goals, students need to be able to identify possible weaknesses in the design and work to improve it. In addition to this, reporting the results of experiments so that they become community knowledge is required for further work with such information to take place. To these ends, the contribution types for obtaining information in science include: *asking for evidence, testing hypotheses, introducing new facts from sources, introducing new facts from experience, identifying a design problem, thinking of design improvements* and, finally, *reporting experimental resu*lts.

iv) *Working with Information:* A scientific theory, or a theory in any other domain, needs to be supported by solid and convincing evidence in required in order to be accepted by the wider community (Darden, 1991; Seixas, 1993). In science, evidence is established through repeated experimentation and corroboration with relevant sources (Darden, 1990). In Knowledge Building, students need to develop habits not only of acknowledging but utilizing observed or established facts as evidence to support their explanatory propositions. Students must also develop the capacity to evaluate evidence brought to bear by others on a particular problem or question. A capacity to use information productively constitutes a movement towards thinking like a scientist working to prove a theoretical claim. Two critical attributes for working with information thus include: *using evidence or a reference to support an idea* and *using evidence or a reference to discard an idea*. In addition to supporting their own ideas with evidence or references, it is important that students develop capacities to productively challenge ideas they think are not useful, as well as respond to similar challenges with valid evidence. Students must also be able to consider a range of claims in order to determine whether one is more sound than another and give reasons for their choices. Finally, accounting for conflicting information requires students to rethink their own claims and ideas in light of contrary evidence. As such, the remaining two contribution types for this category *include weighing theoretical claims based on evidence*, and *accounting for conflicting explanations*. While these represent very challenging moves to make, researchers emphasize that giving students the opportunity to deal with conflicting sources or evidence can help deepen their thinking about various knowledge claims (e.g., Schauble, Glaser, Duschl, Shulze & John, 1995; Wineburg & Wilson, 1991). Embedding the work of assessing and applying evidence in the larger pursuit of constructing coherent explanations provides an approach to classroom work that is analogous to the work of a community of scientists working together to advance scientific frontiers (Chuy, Prinsen, Scardamalia, Teplovs, Resendes et al., 2010).

v) *Synthesizing and Comparing:* This category represents particularly high-level thinking types. For instance, *synthesizing available knowledge* represents an important discourse move in Knowledge Building practice that serves to integrate a diverse range of ideas and information and helps the community to narrow down focus on a particular inquiry. Similarly, presenting a synthesis of ideas from community discussion or authoritative sources calls for students to paraphrase and interpret the information in their own words, communicating the main points and making conclusions based on their own assessments. Synthesizing ideas involves cognitive processes that are quite demanding, especially for young students (Anderson & Krathwohl, 2001). Consequently, this move may not be a frequently made contribution by young students, notably when they are working individually or expressing ideas in writing rather than speaking. However, as a discourse move that is essential for explanatory coherence, its presence in students' explanation-seeking discourse is important and ought to be highly encouraged and supported. Moreover, on occasions where knowledge gaps might prevail and hinder knowledge advancement, the *use of comparisons and analogies* can be extremely useful for driving the discourse forward (Bereiter, 2009) and for inspiring creative thinking (Holyoak & Thagard, 1995). Finally, *initiating a "rise-above" entry* constitutes perhaps the most challenging move in explanation-seeking discourse, as it represents making advances in understanding and successfully coming to higher-level conceptualizations (Scardamalia, 2002). Rising above the current state of community knowledge requires that students not only summarize available ideas, but also try to move beyond them in promising and scientifically sound directions. Original problems of understanding advance to a higher more conceptually difficult level and will, ideally, lead to a new problem space that opens up further possibilities for theory improvement.

v) *Supporting Discussion:* This category represents contribution moves that play a supportive role in the discourse, either socially or in terms of augmenting written work. Contribution types under this heading include *acting as a mediator to discussion, giving an opinion,* and *using a diagram to support an idea*. With respect to socially supportive contribution types, studies exploring gestures that help create a sense of community, such as offering encouragement, giving praise, or apologizing, show that these moves are important for helping to cohere a group and to sustain productive working relationships (e.g. Johnson & Johnson 1989; Slavin 1990). Such interactions are critical in an innovation ecology in which a sense of community is important for maintaining positive group dynamics, as is the case for Knowledge Building (Bielaczyc, 2006; Hakkarainen, 2009). In explanation-seeking discourse, a number of contribution types work to support various aspects of group dialogue. For instance, mediating discussion describes contributions in which students negotiate amongst themselves or deliberate on social aspects of the discussion, which can help create community cohesion. In addition, giving an opinion can help garner community support for an idea. Hatano and Inagaki (1996) report that “partisan motivation” (p. 339) can help drive comprehension activity because it can liven dialogue. Also, opinions can also constitute a primary dialogue act that can be further developed by means of providing evidence or reasoning to support the claim (e.g. Toulmin, 1958). However, it should be noted that because opinions can often reflect “belief-mode” discourse, they can be less useful for advancing an idea than other contribution types (Scardamalia & Bereiter, 2010). Finally, contributing drawings or diagrams represents a contribution type that plays an important role in the construction of scientific explanations (Ramadas, 2009). Recent work exploring the role of drawing in developing students’ scientific thinking asserts that drawing and diagramming can help students to better represent and communicate their own thoughts, and explore increasingly complex ideas (Brooks, 2009; Longo, Andersen, & Wicht, 2002) and assist in problem-solving processes (Larkin & Simon, 1987; Pylyshyn, 2003). As tools to help augment knowledge and communicate ideas, drawings and diagrams play a particularly important supportive role in students’ Knowledge Building discourse.

It should be noted here that his contribution inventory is not exhaustive and does not demonstrate all possible roles important for knowledge creation; rather, this scheme represents a broad number of contribution types critical to explanation-seeking dialogue and can serve as a basis for a more detailed and coherent model. For instance, current work investigating the capacity of young students to engage in “promisingness judgments” represents a vital aspect of Knowledge Building work that remains unaddressed in this inventory (see Chen, Resendes, Chuy, Tarchi, Scardamalia & Bereiter, 2011). Similarly, new advancements in technologies for Knowledge Building environments might include more sophisticated drawing tools or methods of annotating objects imported from a variety of sources. Thus, the ways in which “visual thinking” processes (e.g. Ware, 2008) play a role in students’ Knowledge Building discourse, including both the capacity to create images, as well as those involved in deciphering and interpreting images, could be interrogated in more depth. However, the existing scheme is a valuable resource as it covers a wide range of contribution types that one can expect to encounter in elementary-aged students' explanation-seeking discourse, as well as those that ought to be encouraged in the classroom to help young students develop their capacities for constructing increasingly coherent explanations.

In a study exploring the discursive makeup of two Grade 4 classes based on the original version of the above inventory, Chuy, Resendes & Scardamalia (2010) found that a high proportion of the respective dialogues were dedicated to theorizing and introducing new information, and that introducing new and interesting facts as well as the capacity to use evidence or a reference to support a theory played a dominant role in theory improvement for these junior level students. Findings from this study support similar research that found that continual co-ordination between empirical evidence and theorizing efforts is necessary for young students to improve scientific explanations and to develop deep understanding (Klahr & Dunbar, 1988; Zhang, Chen, Sun, & Reid, 2004). Taken together, this literature shows that the more connections students make between certain theories and the facts they introduce into the discourse, the more likely they are to improve their own ideas. These findings align with the notion of 'explanatory coherence' (Thagard, 1989, 2007) and help to describe the quality and characteristics of discourse that reflects productive and progressing knowledge work.

Studies that identify meaningful contribution types to collaborative discourse not only offer researchers a glimpse into important social and cognitive aspects of collaborative work, but can also provide a means to assess students' dialogue, and to earmark important contribution types that can serve as targets for innovative design work. For instance, identifying the various contributor roles conducive to effective dialogue is becoming the basis for the development of innovative automated technologies that can mine and map online discourse for important discursive patterns and interactions. The proceeding section expands on this topic, and provides an in-depth discussion on new technologies to support explanation-seeking discourse in collaborative computer-supported environments.

2.4 Emergent Technologies: Supports for Collaborative Discourse

In the past decade, research dedicated to the design of learning environments that support collaboration has grown rapidly (Dillenbourg, Eurelings, & Hakkarainen, 2001; Koschmann, Hall, & Miyake, 2002; Koschmann, 1996). Innovations to support productive collaborative discourse in online learning environments have also increased considerably (e.g., Guzdial & Turns, 2000; Lipponen, et al, 2002; Werigoff, 2006). Important advances in this area include the development of tools that can perform automated recognition of contribution types in dialogue structures to enhance discourse-centered platforms (e.g. Kral, Laprie, Kleckova, 2007; Rosé, Wang, Cui, Arguello, Stegmann, Weinberger, & Fischer, 2008). This research has been motivated in large part due to the growing recognition that simply asking students to talk together in an online space does not necessarily lead to high-level discourse (cf. Kreijns, Kirschner, & Jochems, 2003). For instance, popular educational environments such as Moodle (Cole & Foster, 2007; Martín-Blas, Teresa, Serrano-Fernández, 2009) or Druple (Fitzgeraled, 2008), or learning management systems such as WebCT and Blackboard (Kent & McNergney,, 1999), support a wide range of activities and include components that support discourse such as discussion forums and messaging systems. Similarly, Wikis, which have also grown in popularity as a tool for collaborative learning (e.g. Bryant, Forte, Bruckman, 2005; Papert, 2000), include useful features such as accessibility to extended networks (Surowiecki, 2004), and the ability to co-construct shared documents (Aguiton & Cardon, 2007). However, the capacities of these new tools and environments to support knowledge creating discourse are limited (Scardamalia & Bereiter, 2003). For instance, the literature on asynchronous online discussions shows that such dialogue consistently demonstrates disappointing levels of engagement and knowledge advancement (Pifarre & Cobos, 2010). In threaded discussion environments, for example, discourse often does not go beyond "conversations" that feature an abundance of opinion and idea sharing but lack any significant depth of inquiry or advancement of collective knowledge (Hewitt, 2001; 2003). Similarly, while Wikis provide exciting new opportunities for collaborative writing and information sharing, Bereiter and Scardamalia (2010) point out that the goal of constructing a Wikipedia entry, as established by Wikipedia, is to represent the state of knowledge rather than advance it. While media of all sorts can be turned to different purposes, biases for a certain form of discourse tend to be embedded in their designs. For example, social media such as Facebook and Twitter represent dialogue in threaded format, which is rendered according to chronology rather than any semantic or conceptual structure; thus, while these forms of media certainly inspire dialogue, they are not designed to support sustained knowledge creating discourse (Scardamalia & Bereiter, 2006).

As noted above, research that explores the development of automated tools to mine and model effective dialogue acts is growing, and is driven by the objective to support high-level discourse in computer-supported collaborative environments. A large body of this research focuses on innovations to enhance argumentative dialogue in particular (e.g. Andriessen, Baker & Suthers, 2003; Bell, 2002, 2004; Klein & Iandoli 2008; Weinberger, Stegmann, Fischer, & Mandl, 2007). For example, the use of representational guidance to boost scientific argumentation was the focus of the development for the "Belvedere" program (Suthers, 2001; Suthers & Weiner, 1995; Toth, Suthers, & Lesgold, 2001). The Hermes environment, (Karacapilidis & Papadias 2001) and the CoPe_It! platforms (Karacapilidis & Tzagaraki, 2009) are similarly designed to support argumentative collaboration. The Rainbow program (Baker, Adreissen, Lund, Amelsvoort, Quignard, 2007) is designed to support scientific debate and argumentation, while Collaboratorium (Klein & Iandoli 2008) and Legalese (Hair, 1991) are platforms created for legal argumentation. Finally, Compendium (Buckingham Shum, Uren, Li, Domingue & Motto, 2003) is an environment developed to support large-scale collaboration or decision-making for "wicked problems", based largely on an argumentative framework.

This emphasis on argumentation is also evident when looking at new technologies designed to identify salient contribution patterns within a given dialogue. For instance, the TagHelper tool designed by Rosé et al. (2008) identifies contribution types from individual student notes in online discourse and uses machine learning techniques to detect meaningful event sequences from logs of student discussion. Sequences are based on an argumentative framework and include discursive interactions such as a "Chain of Opposition", in which students debate an issue back and forth, as well as "Deepening" and "Widening", which represents creative reasoning and the emergence of new ideas. The overall goal of this tool in practice is the automatic aggregation of fine-grained patterns of student discourse that can serve to summarize discussions, to develop models of aggregated information, and to provide formative feedback based on these models. Similarly, the "Argunaut" project (McLaren, Scheuer, & Mikšátko, 2010) is designed to acquire "meaningful indicators" derived from student discourse that can inform online feedback and alerts that can be used by moderators of synchronous online discussions. Researchers developing this tool were interested in automatically identifying significant contribution and discourse patterns using artificial intelligence techniques, with a specific focus on critical reasoning and argumentative dialogue. Another example is The Discourse Analysis Tool (DAT) created by Jeong (2003). This tool enables researchers to examine student interactions and critical thinking acts taking place in threaded discussions. The technology is designed to automatically identify dialogue event sequences that reveal significant patterns of student interaction. Finally, De Liddo Buckingham Shum, Quinto, Bachler, & Cannavacciuolo (2011) are developing discourse-centered learning analytics that can mine collaborative discussion and classify a particular individual's contributor role within group dialogue (e.g., question-asker, fact gatherer, etc.), as well as the rhetorical moves evident in a contribution (e.g., response to an argument, answer to a question, counter-argument provided to a claim, etc.). Such a tool could provide valuable information about important social and individual aspects of group dialogue, including salient discourse patterns and the contribution profiles of participants, as well as how these elements might interact in a discourse.

These environments represent important advances in educational technology and promising design components of emerging Knowledge Building online environments. However, if the goal is to utilize such tools in order to support high-level knowledge work, then these tools and their supporting architecture need be specially tailored to enhance discourse oriented towards knowledge creation. Currently, most contemporary environments and technologies subdue features that are essential to knowledge building environments (Scardamalia, et al., 2012), which include supports to help students to collaboratively improve ideas, sustain emergent inquiry and continually move discourse forward towards a knowledge building goal (Scardamalia & Bereiter, 2006). Technology that supports collaborative explanation seeking discourse includes designs to help students make a diverse and productive contributions to collaborative discourse, features multiple ways of representing and working with ideas, and provides a means to let students revise and build upon previous ideas (Bereiter & Scardamalia, 2003, p. 20). A more in-depth discussion of technologies built for knowledge creation can help to distinguish the essential features of Knowledge Building environments from existing designs and to introduce new possibilities for supporting high-level discourse within collective computer-supported environments.

2.4.1 Knowledge Building Environments: Knowledge Forum

The Knowledge Forum (KF) online environment is the technology specially designed to support knowledge creation processes, the emergence of big ideas, shared goals, and principle-based Knowledge Building pedagogy (Scardamalia, 2004). The pervasiveness of Knowledge Building affordances embedded in the Knowledge Forum environment are designed to support students in dealing with complexity and doing high-level knowledge work. In Knowledge Forum, students enter questions, evidence, and so on, as *multimedia notes* into a collective knowledge space (see Figure 2). Students can *build on, annotate, co-author,* and create *rise-above* notes, which represent higher-level conceptualizations. These notes can be organized thematically within *views*, which serve as a collective knowledge spaces. An important feature within Knowledge Forum is the verbal *scaffolds* that are embedded within the note interface (see Figure 3). Scaffolds represent a variety of epistemological terms (such as "My theory", "I need to understand", etc.) and are designed to help frame students thinking and encourage a range of important discourse moves. Scaffolds can be customized to be optimal for different contexts and facilitate growth in conceptual content.[1]

Studies have shown Knowledge Forum to effectively support explanation-seeking dialogue and deep inquiry across various domains, including science and technology, social sciences, and ethics (Hamal, & Turcott, 2012). Niu and van Aalst (2009) found Knowledge Forum supportive of Knowledge Building across academic levels, with significant improvement in quality of

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[1] Knowledge Building scaffolds will hereafter be placed in quotation marks in this thesis.

discourse in short time periods. Use of this environment has resulted in significant gains in literacy as a byproduct of Knowledge Building work (Scardamalia, et al., 1992).

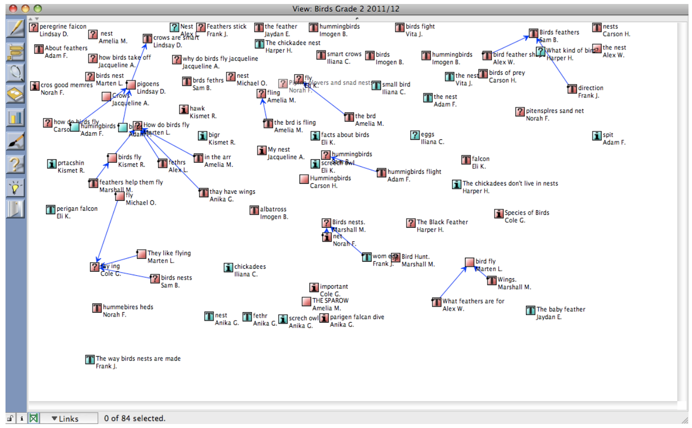

Figure 2. A Knowledge Forum *view* populated with *multimedia notes* (square icons).

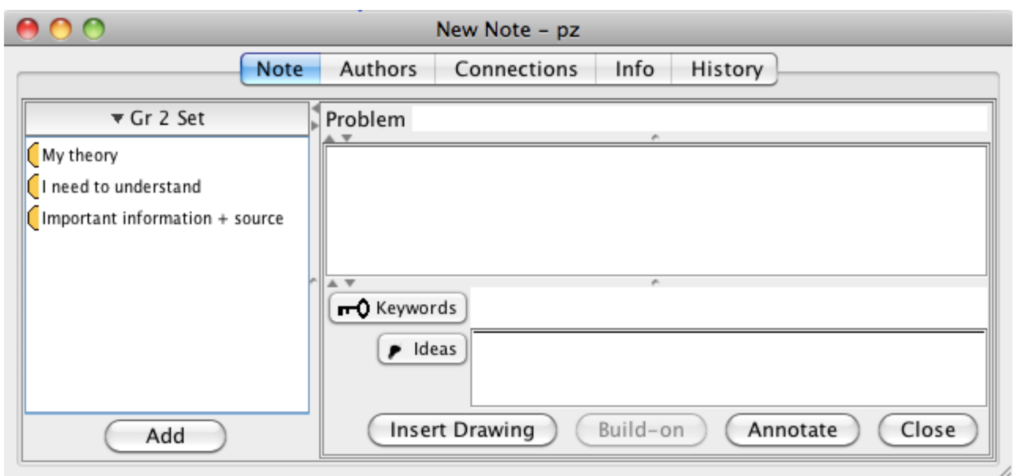

Figure 3. An open note in Knowledge Forum, with a "Theory-Building" scaffold (left-hand panel of the note).

2.5 Next Generation Knowledge Building Environments

Knowledge Forum is unique among computer-supported collaborative environments in its design to support fundamental aspects of knowledge creation. Emerging Web 3.0 technologies open up important new possibilities and research and development efforts are underway to design next generation Knowledge Building environments that can support coherent and sustained discourse across media platforms and make use of the most promising innovations to support critical Knowledge Building processes (see Scardamalia, 2010 for more on these initiatives). For instance, important dimensions include an architecture to maintain one sustained discourse with multiple entry points across platforms, supports for metadiscourse, promising ideas, rising-above, as well as tagging and citing to promote idea improvement, as well as features to promote ubiquitous theory building and self-organization beyond division of labor. Other critical elements include user-designed spaces for knowledge advancement, and the ability to make any media object an object of Knowledge Building discourse.

Another high-priority objective for this initiative is the design and development of embedded, concurrent and transformative assessments for knowledge creation (see Scardamalia, Bransford, Kozma, & Quellmalz, 2010). New assessments provide a crucial method for scaling up Knowledge Building in practice, as the development of computer supports to facilitate the processes required for knowledge creation can help to make a Knowledge Building pedagogical approach more widely accessible (Scardamalia, et al., 2010). However, in order for new assessments technologies to be successful, they need to be meaningful and accessible to both teachers and students themselves (van Aalst, Chan, Chan, Wan, Chan, & Teplovs, 2010, p. 3). In the following section, I elaborate on the criteria for assessments designed to guide knowledge creation. More specifically, I introduce formative assessments as modes of assessment that are particularly suited to support diverse and high-level ways of contributing to explanation-seeking discourse, and explore the ways in which they present promising approaches to help boost student capacities for Knowledge Building work.

2.5.1 Formative Assessments

Traditionally, assessment was thought of as separate from the learning process, concerned wholly with ranking students and testing their performance (Shepard, 2000). However, current views regard assessment as a valuable method of scaffolding and enhancing student learning, in addition to measuring performance and achievement (e.g. Black & Dylan, 1998; Crooks, 1988, Biggs, 1996; Gipps, 2002). The distinction between 'assessment of learning' and 'assessment for learning' is useful for delineating the different purposes and functions of assessment (Black & William, 1998). For instance, "assessment of" learning is primarily summative, that is, it focuses on obtaining grades for evaluating and reporting students' performances corresponding to predetermined objectives and established procedures, and include things like tests and exams. "Assessment for" learning, on the other hand, is primarily formative; that is, it presents ongoing feedback to students throughout the learning process, makes learning objectives explicit, orients students towards goals, and provides support to students regarding ways to deepen their understanding and improve achievement. The concept of formative assessment utilized in this research is aligned with the definition offered by the Formative Assessment for Students and Teachers (FAST) organization, which describes it as a "process used by students and teachers during instruction that provides feedback to adjust ongoing teaching and learning to improve students' achievement of intended instructional outcomes" (Heritage, 2010, Foreword).

The use of formative assessments to enhance learning is widely recognized (Broadfoot, 1996; Black & William, 1998; Crooks, 1998; Marzano, 2003; 2006; Scriven, 1967; Stiggins, 2004; Stiggins, Arter, Chapius & Chapius, 2006). Formative assessment can be particularly beneficial for promoting self-regulation (Butler & Winne, 1995; Winne & Hadwin, 1998) and has been shown to help low-performing students achieve greater levels of success (Blook, 1998; Stiggins, 2004; Stiggins & Chappuis, 2005). Similarly, peer assessment has been shown to provide positive "backwash" effects on learning and collaboration (Biggs, 1996). Furthermore, a growing body of assessment-oriented research in the field of computer-supported collaborative learning (CSCL) show benefits of online supports for helping students communicate, reflect and revise ideas (Tseng & Tsai 2007), increase motivation and engagement (Chen & Tsai, 2009; Vye, Schwartz, Bransford, Barron, Zech, et al., 1998; White, Shimoda, & Fredericksen, 1999) and foster collaboration (e.g., Koschmann, et al., 2002).

Alongside these advances, however, other research focusing on use of formative assessments in computer-supported environments has shown that even when studies purport high-level goals and outcomes, assessment can often remain on the level of superficial knowledge (Reeve, 2000). Similarly, while much attention has been given to exploring assessments designed to support collaboration and interaction in collaborative online environments in recent years, more research is needed to determine how these processes lead to conceptual advances and deeper understanding (Bereiter, 2002; Chan & van Aalst, 2004). Chan and van Aalst (2004) argue that discrepancies between assessment innovations and the outcomes they measure indicate "a fundamental problem with the alignment of assessment, learning, and collaboration in both research and teaching contexts" (p. 91). New formative assessments need to be in line with the pedagogical models that underpin them and ought to support and characterize deep inquiry, student agency, as well as collaboration (Chan & van Aalst, 2004; Lee, Chan, & van Aalst, 2006).

In a comprehensive discussion about formative assessments that target 21st century competencies, Scardamalia et al., (2012) outline four critical functions of effective feedback, which include the capacity to: "Make student thinking and reasoning processes visible; Support formal and informal forms of collaboration and social networking; Represent temporal, causal, dynamic relationships "in action"; Allow multiple representations of stimuli and their simultaneous interactions" (p. 269). Moreover, in order to remain aligned with the pedagogy and practice that they are meant to enhance, designs for new formative assessments need to informed by all aspects of the pedagogical process—how a domain is approached in practice, how it is taught or approached in various contexts, and how students are engaged in learning (Scardamalia, et. al., 2012). These criteria offer important methodological guidelines to support the development of new assessments that can productively bootstrap important and challenging knowledge construction processes.

2.5.2 New formative assessments for Knowledge Building

van Aalst et al. (2010) describe formative assessment in the context of Knowledge Building practice as the following: "the collection of information involved in students' own inquiry into their knowledge building. It is not epistemologically distinct from knowledge building, except that the domain of the inquiry is not subject matter (e.g., science concepts) but the process of knowledge building" (p. 6). Formative assessments designed to guide creative work with ideas do not only provide backwash effects but also, more importantly, feed forward into the work of teachers and students as it carries on. In other words, formative assessment to support knowledge creation ought to not only help bring students closer to a specific curricular target or objective, but should work "to increase the distance between present performance and what has gone before, opening the door for exceeding targeting outcomes" (Scardamalia et al., 2012, p. 243). Assessments built to guide the most important dimensions of Knowledge Building practice need to visualize data in simple representations that are easy for both students and teachers to use in practice, but need also to be powerful enough to help boost both the socio-behavioural and cognitive processes necessary for knowledge creation to occur (Yang, van Aalst, & Chan, 2012).

Existing assessments for Knowledge Building, embedded within the Knowledge Forum environment, are designed to capture and support both individual and social aspects of students' Knowledge Building discourse. For instance, the Knowledge Form Analytic Toolkit® (ATK)

(Burtis, 1998) supports internal monitoring and improvement of a community's work and includes a suite supports such as social network visualizations and displays of individual and collective contribution patterns (e.g., Palonen & Hakkarainen, 2000; Zhang et al. 2009). Studies have shown a relationship between Analytic Toolkit indicators (notes created, notes read, scaffold use, and note revisions) and evidence for knowledge building (Lee et al., 2006; van Aalst & Chan, 2007). Knowledge Forum also features a suite of Java applets that include tools for tracing socio-cognitive behaviours such as trends in reading and writing (Teplovs, Donahue, Scardamalia, & Philip, 2007). Another feature integrated within the online environment are automated tools that support emergent knowledge growth, such as the Custom Search tool. This tool allows teachers or students to gain "just in time" access to a variety of relevant authoritative sources that correspond directly to the concepts that students themselves are discussing and exploring. Finally, an innovative software platform that is not directly integrated within Knowledge Forum but is designed to easily extract the data it generates is the Knowledge Space Visualizer (see Teplovs, 2008) This program is driven by semantic analysis and affords a multitude of ways to represent and explore archived discourse, including the ability to map semantic connections and overlap occurring between student dialogue and expert discourse taken from resources such as authoritative texts or curriculum guidelines.

These tools and platforms provide valuable means of exploring the discourse students generate on Knowledge Forum. However, as they stand many of these tools are too difficult for students, especially those in elementary grades, to use in practice (van Aalst, et al., 2010; van Aalst, et al., 2007). As noted, the design of next-generation assessments for knowledge creation need to combine powerful analytics, such as those that underlie the technologies described above, with user-friendly visualizations and interfaces. Currently, there are a number of cutting-edge research programs developing innovative technologies that can be leveraged to support critical aspects of Knowledge Building such as improvable ideas (Kump, Seifert, Beham, Lindstaedt, & Ley, 2012; Rose & van Lehn, 2005; Sherin, 2012; Teplovs Fujita, & Vetrapu, 2011) explanatory coherence (De Liddo et al., 2011; Graesser & McNamera, 2011), conceptual change (Larusoon & White, 2012), metacognition (Santos, Govaerts, Verbert, & Duval, 2012), and community and social dynamics (Ferguson & Shum, 2012; Paredes & Chung, 2012). Harnessing the power of these new technologies in the interest of knowledge creation, however, will require that their design be grounded in the foundational principles of Knowledge Building and their implementation consistent with the pedagogical model.

2.5.3 Next generation formative assessments for Knowledge Building

There are a number of examples of innovative technologies that illustrate effective examples of new assessments for Knowledge Building. For example, van Aalst & Chan (2007) and Lee, Chan, & van Aalst (2006) tested designs for electronic portfolio assessments to boost Knowledge Building discourse in Knowledge Forum with positive outcomes, including deeper inquiry and greater conceptual understanding. This research formed the basis for the development of the Knowledge Connections Analyzer (KCA) (van Aalst, Chan, Tian, Teplovs, Chan, & Wan, 2012), a discourse-centered assessment tool developed to be used specifically by students and teachers throughout their Knowledge Building work. The Knowledge Connections Analyzer works in conjunction with Knowledge Forum to provide visual feedback on semantic aspects of the online discourse. This new assessment system includes tools to analyze e-portfolios, but also provides ways for Knowledge Building communities to make reflective assessments during their own knowledge creation practices. Data is generated from Analytic ToolKit indicators and is based on questions that students might typically ask of their own work, such as: Are we collaborating? Are we putting our knowledge together? What happens to ideas over time? What's happening to my ideas? In this way, the system differs from existing tools such as the Analytic ToolKit in that it is "student-driven" rather the "data-driven," making it usable for students and teachers at virtually any grade level.

Another innovation for exploring explanation-seeking discourse within Knowledge Forum is KBDeX (Matsuzawa, et al., 2011; Oshima, Oshima, & Matsuzawa, 2012). This tool performs network structure analysis and explores group-level dynamics on a range of levels—for instance, dialogue can be mapped textually at the levels of notes, sentences, words, or socially by tracing the activity of individual or select groups of student users. Using social network analysis, this tool produces simple and customizable interfaces and network visualizations that are designed to be accessible to both students and teachers alike. More than this, KBDeX also includes more advanced features such as tools enabling phase and stepwise analysis for researchers wishing to explore more complex attributes and dynamics in student discourse (see Oshima, Oshima, & Matsuzawa, 2012). Taken together, these new technologies represent important advances driving the designs of new assessments for enhancing Knowledge Building work.

2.5.4 Formative feedback to support ways of contributing to explanation-seeking discourse

Alongside the developments described above are new assessment tools that focus on specific attributes of explanation-seeking discourse that have until very recently been given much less attention theoretically and technologically. These are the concepts of "promisingness", or making "promisingness judgments", as well as "Metadiscourse", respectively. As mentioned in Section 2.3.4, "promisingness judgments" are characteristics of creative experts and are critical to knowledge creation processes (Bereiter, 2002; Bereiter & Scardamalia, 1993). For instance, whether or not a certain idea will end up being valuable to a Knowledge Building community is often difficult to ascertain at first. However, in order to advance knowledge it is necessary that promising ideas be identified in order for community members to avoid wasting time on ideas that are potentially less useful to the central goal. Indeed, an important part of acquiring expertise and becoming a creative knowledge builder is learning to take calculated risks with ideas, and learning from the successes and failures of choices made in the process of inquiry (Bereiter & Scardamalia, 1993). The Big Ideas Tool (Chen, et al., 2011) is a new tool integrated within Knowledge Forum that is designed to help students make "promisingness judgments" on their own ideas. This tool allows students to reflect on the ideas their community has produced and to select the ideas that they deem most promising, and thus wish to develop further. The Big Ideas tool not only helps students to actively move their knowledge forward but also engages students in practicing evaluating their own ideas for promisingness, which is a challenging yet vital aspect of creative knowledge work.

Another new feature for Knowledge Forum is the "Metadiscourse Tool" (Chen & Resendes, 2012). Efforts to establish a more coherent account of the concept within Knowledge Building theory are in progress (e.g. Baltzersen, in press), but for this research, "Metadiscourse" is understood as discussion about discussion, and calls for community members to take a "meta-perspective" and reflect on the state and direction of their own dialogue. Metadiscourse can serve as a type of formative evaluation that can help a knowledge creating community both assess their achievement up to the current point and decide on a future plan of action. Metadiscourse can encompass social aspects and group dynamics, however focus on these kinds of attributes in Metadiscourse ought to be "subordinate to the over-riding issue of whether the dialogue is progressing" (Bereiter & Scardamalia, 2010, p. 5). While Metadiscourse can be valuable to the advancement of the dialogue as a whole, it represents a discourse move that is peripheral to the "central path" of the dialogue and as such, is often neglected in practice (Bereiter & Scardamalia, 2010, p. 4) and lacking in online discussion (Scardamalia & Bereiter, 2006a). The Metadiscourse Tool was built to provide support for this important element of knowledge building discourse, and is specifically designed to facilitate Metadiscourse about the contribution makeup of group dialogue by giving students a “birds-eye view” of the ways they are contributing to their own discourse.

The Metadiscourse Tool works in tandem with Knowledge Forum scaffolds, which have been a key feature in Knowledge Forum throughout its 30-year history (Scardamalia, 2004). The Metadiscourse Tool is embedded within the Knowledge Forum environment, and stores data from students’ activities as they work on the database. More specifically, every time a student uses a verbal scaffold in their note, the Metadiscourse Tool automatically stores this information, keeping a record of all the scaffolds that are being used in a particular discourse. The metadiscourse visualization is activated by clicking on a small scaffold icon on the main Knowledge Forum interface, which then opens up a separate window showing a simple bar graph that displays patterns of scaffold use, allowing the community to track the various sorts of contributions that are being made to a shared knowledge base at any given time. Students are also able to easily identify those contribution types that they are *not* making and which may present particular difficulties by their absence in the graph. For instance, a visualization that fails to show activity for the “Putting our knowledge together” scaffold indicates a potential lack of community effort to synthesize available knowledge. The simple graph is accessible to students from a range of ages and provides a simple yet powerful visual to facilitate reflection on important attributes of shared dialogue, for instance, whether a particular discourse is saturated with questions but relatively few ideas, or whether there is an abundance of outside information but no connections between facts and students’ own theories.

As van Aalst (2006) points out, it is critical that students possess an understanding the nature of explanation-seeking discourse in order for automated assessments to be meaningfully integrated within the routines of their Knowledge Building work. More than this, assessments ought to help students develop and deepen such understandings through their use. The Metadiscourse Tool can help foster deep understanding of the nature of explanation-seeking discourse by presenting group-level data that can be used to initiate and facilitate whole class, reflective discussion about the contribution types that make up the community's discourse at any given time in the inquiry, including why different contribution types might be important at different times. While the Metadiscourse Tool's visual feedback takes very simple form, it leverages the power of the scaffolds to provide valuable information regarding the contribution makeup of a particular discourse that can enhance students' interactions with the Knowledge Forum environment. For instance, the bar graph provides a record of students' scaffold use that can feed directly into future episodes of Knowledge Building work—namely, periods of personal or collective reflection. Thus, the tool provides incentive for students to use the scaffolds to frame ideas when composing notes, which has been shown to directly benefit students' efforts to create new knowledge and deepen their own understanding (Chuy, et al., 2009; Lai & Law, 2006). Targeting scaffold use for contribution-oriented formative assessment also provides a means to fluidly move between discourse moves that are both central and peripheral to the "central discourse path" of a Knowledge Building community. For instance, when students use scaffolds to frame their own contributions, they are explicitly identifying a "thinking type" or "way of contributing" to group dialogue (posing a question, synthesizing ideas, contributing useful information, etc.) as they are writing their note. This process facilitates metacognitive awareness on behalf of students about their own discourse, as they become more conscious of how they are contributing to the online dialogue. Metacognitive awareness can thus be heightened when students are invited to focus and reflect on the patterns of scaffold use in their discourse by collectively exploring feedback that visually displays this data. Indeed, research shows that formative feedback that supports “meta-perspectives” has been found to help students develop metacognitive awareness, collaboration skills and creativity (Nunes, Nunes & Davis, 2003). Moreover, engaging students in discussion around the scaffolds in the Knowledge Forum environment can help metadiscourse (Scardamalia & Bereiter, 2006a). By detecting and displaying contribution patterns, feedback provided by the Metadiscourse Tool can help to highlight underrepresented contribution types and bring neglected elements of the discourse to the forefront of students' attention (Scardamalia et al., 2012). Thus, making different types of contributions and then evaluating the ways these contributions are coming together (or failing to come together) in a discourse becomes an seamless process that students can engage in as a community and is explicitly supported by the features available within the technology. For educators and researchers interested in innovations to boost student capacities to contribute diversely to explanation-seeking discourse, the Metadiscourse Tool represents a promising new support.

2.5 Chapter Summary

This chapter began with a description of Knowledge Building theory and its underlying principles. Following this, I discussed the concept of discourse as a medium for creating new knowledge and provide an overview of important ways of contributing to collaborative explanation-seeking discourse. Next, new technologies for supporting high-level discourse in computer-supported collaborative learning environments was explored, with an emphasis on discussing research advances in the design and use of innovative assessments for boosting collaborative dialogue. The chapter concluded with a more narrowly focused consideration of formative assessments designed for new Knowledge Building environments, with an emphasis on exploring the use of tools to support reflection and ongoing evaluation of ways of contributing to explanation-seeking dialogue.

CHAPTER 3: METHODOLOGY

3.1 Chapter Overview

In this chapter, I lay out the methodological approach guiding this research. I begin with an introduction to design-based research, and discuss both its characteristics as well as the challenges it presents. Next, I discuss the "co-design" approach, which is a design-oriented method that is complementary to design-based research. Included in this discussion is an overview of the benefits and difficulties of this approach to the proposed study. I follow this with a general description of the setting and the participants involved in the research. Next, I provide a very brief overview of the three phases of the study and their corresponding objectives. Finally, I conclude by providing a detailed account of the data sources for the study, and comment briefly on how each source will be utilized in data analyses.

3.2 Design-Based Research

This research tests pedagogical and technological tools that are grounded in Knowledge Building principles and are designed to support emergent learning. A flexible methodological approach that accommodates multiple design cycles and progressive design refinements is therefore required. The method that best fits the needs of my research is a design-based research approach (Brown 1992; Collins, 1992). Many definitions of design research exist, but for the purposes of this study it is sufficient to explain this paradigm as "any kind of research producing findings that are fed back into further cycles of innovative design" (Bereiter, 2006, p. 17). Because curriculum development, methods of assessment, and the influence of the teacher are all tightly bound up together in the classroom, they cannot be examined independently in a real world context without disrupting the flow and dynamic of the classroom itself (Bielaczyc &

Collins, 2006). Thus, if researchers wish to develop innovations to enact a theory-based pedagogy that can become integral to the day-to-day operations of a classroom, testing designs that inform that practice must take place in that very context (Brown, 1992). Developed to facilitate rigorous studies in "live" scenarios, a design-based approach is especially useful to "help create and extend knowledge about developing, enacting, and sustaining innovative learning environments" (Design-Based Research Collective, 2003, p.5). As Bereiter (2006) points out, due to the growing prevalence of information technologies in education, design-based innovations for education should also include technological improvements along with advances in pedagogy and theory. Thus, a design based research approach for this research, which is concerned with testing educational innovations designed to boost students' competencies in explanation-seeking discourse, is appropriate.

3.2.1 Characteristics of Design Research

Design research is conducted in real-world contexts which cannot be fully controlled, and as such take place in very different conditions than laboratory or other highly-monitored experiments (Bielaczyc, & Collins, 1999; Collins, Joseph & Bielaczyc, 2004; Wang & Hannafin, 2005). Design-based research for education is concerned with the innovation of educational tools in real world contexts, the advancement of both practical and theoretical developments, and the pursuit to understand more deeply the relationships between them (Design-Based Research Collective, 2003). Due to the highly contextualized nature of design research, this approach does not have a fixed methodology but is often comprised of an integration of a variety of qualitative and quantitative approaches. All aspects of design research are supported by a theoretical framework that both underpins any resulting innovations and is itself the subject of continual development and elaboration (Collins et al., 2004; Wang & Hannafin, 2005) Goals of design-based research for education include guiding theory development, improving instructional design, generating contextually-dependent yet robust and generalizable design principles (Wang & Hannafin, 2005), identifying new design possibilities (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Edelson, 2002), and impacting change in real-world settings (Bereiter, 2006). Emphasizing the utilitarian dimension of the approach, Kelly (2004) asserts that, "design studies should produce an artifact that outlasts the study and can be adopted, adapted, and used by others" (p. 116). Design-based research is much more likely to result in such an outcome and lead to effective real-world impact and application because it is conducted in real-life settings, and because researchers collaborate closely with practitioners, engineers, and any others who operate within the given scenario or context (Design-Based Research Collective, 2003).

3.2.2 Challenges of Design Research

Despite its many benefits, there are significant challenges to design research in educational settings. First, classroom environments are constantly in flux. Whereas the design researcher is not able or interested in controlling for all variables, she must consider all aspects of the environment as having a potential impact on those individual or few variables of particular interest. Thus, large amounts of both quantitative and qualitative data need to be collected and analyzed. This often requires large amounts of time and resources from researchers, as well as co-ordination of work. Second, aspects of classroom life and activity, such as spontaneous dialogue and interaction, are very difficult to capture and quantify. Third, causes for particular success or failures of educational interventions may be the result of a myriad of factors, making definitive claims difficult to put forth. Triangulating data, utilizing standardized research instruments, or applying identical coding schemes or measures of analysis across design iterations can be used to help increase the validity and reliability of findings in a design-based study (Design-Based Research Collective, 2003). Fourth, because design-research is focused on "progressive refinement" (Collins et al., 2004) of educational artifacts, practices and theories, greater amounts of time are required to both implement developments and to compare progress across time. A shared commitment to research on behalf of all parties involved must be sustained to ensure successful innovations (e.g., Linn & Hsi, 2000). Last, recent methodological advances in design experimentation (e.g. Cobb et al., 2003; Nash, Plugge, & Eurelings, 2001) show that using conventional experimental-controlled comparison studies to evaluate the efficacy of collaborative computer environments can be problematic, and suggest that exploring how different elements of these environments might interact and impact learning is more useful and fitting for a design approach, which is concerned with developing innovations in "real-world" conditions.

For this thesis research, the Knowledge Forum database provides a rich textual resource, and provides the primary data source of student work. Any insights or progress students show through spontaneous discussion or classroom activity will not be subject to quantitative tests but will serve as important contextual information. Moreover, because the context within which experimentation takes place is largely uncontrolled, I adopt approaches such as data triangulation and application of identical coding schemes across iterations to help improve the validity of study results. While a general overview of data sources and approach to analyses is described in Section 3.7 of this chapter, details corresponding to various analyses are more deeply elaborated in subsequent chapters that describe the corresponding studies in full. Finally, when addressing different participant cohorts I adopt the term "benchmark" or "comparison" rather than "control" to refer to groups that generated work in naturally occurring conditions, and use this data to make comparisons to experimental groups who are subject to varying kinds of treatments during the course of the study. While the benchmark and experimental groups participated in each of the study's two design iterations, they operated in virtually identical environments—both groups attended the same school, had the same teacher for the same grade, and completed the same units of study—all participants were working in highly complex and dynamic settings both online and offline. Thus, it was necessary to reject the traditional labeling of "control" and "experimental" groups for this study and adopt a different terminology.

3.3 Co-Design

As noted, the sustained co-operation and commitment from all stakeholders involved in a design research project is vital to its success. Deep levels of engagement can be supported through the active involvement of each party within the design process. In this research, it was important that the treatments were embedded within the existing Knowledge Building practice of the participating Grade 2 classes and were integrated seamlessly within students' routine activities. A close working relationship between the teacher and I was necessary in order to fit the treatments within her regular practice. As such, a co-design approach was adopted (Roschelle, Penuel, & Shechtman, 2006). "Co-design" is a design-oriented method that "relies on teachers' ongoing involvement with the design of educational innovations, which typically involves technology as a critical support for practice" (Penuel, Roschelle, & Shechtman, 2007, p. 52). More specifically, a co-design approach can be defined as "a highly facilitated, team-based process in which teachers, researchers and developers work together in defined roles to design an educational innovation, realize the design in one or more prototypes, and evaluate each prototype's significance for addressing a concrete educational need" (Penuel et al., 2007, p. 53).

The flexibility of the co-design approach, which requires a considerable level of give and take between stakeholders, is compatible with design-based research and shares similarities with other user-oriented approaches, such as scenario-based design (Carroll, 1995) or participatory design (Muller & Kuhn, 1993). Although it shares commonalities with these methods, seven foundational characteristics help to distinguish co-design from other approaches, including the objectives to i) tackle a tangible innovation challenge ii) work from knowledge of existing classroom context and practice, including elements of classroom and school culture iii) maintain a flexible curricular target iv) participate in shared experiences to deepen shared understanding about the research v) uphold well-defined roles and mutual understanding of responsibilities vii) centralize accountability on the principal investigator. These characteristics support effective collaboration while upholding the unique responsibilities, knowledge base and skills of all stakeholders.

Engaging various parties into the design process brings together diverse perspectives and skills, and can generate methods of practice that hold value and validity to all members. Adopting a co-design approach for assessment-oriented research can also enhance the collaborative dimension of a study, as all parties can play a part in formulating criteria for assessment (Sluijsmans, Moerkerke, van Merrienboer, & Dochy, 2001). Including teachers directly in the design process of educational innovations also decreases the chances for a "lethal mutation" (Brown & Campione, 1996, p. 292) where enactment of that innovation diminishes the principles on which it is built. In addition to this, a co-design approach has been found to benefit teachers' professional and intellectual development (Baird, Mitchell, & Northfield, 1987). This is an important point to note for research that involves a pedagogical approach that requires teachers to turn "collective cognitive responsibility" (Scardamalia, 2002) over to students. The shift from a teaching model in which the teacher is the central authority that engineers, designates and oversees all work, to one which has the teacher facilitate an emergent learning process where students are responsible for strategic cognitive activities, often requires significant support and reflection (cf. Anderson & Roit, 1993; Scardamalia, 2002). A co-design approach provides an environment of knowledge sharing and support that is important for helping to create and sustain a dynamic and self-organizing Knowledge Building community in the classroom.

Co-design can be a useful strategy for educational researchers to adopt in order to test ideas and create innovations, and has resulted in a number of educational advances, including curriculum materials for science (Peters, 2010; Reiser, Tabak, Smith, Steinmuller, & Leone, 2001) and math (Roschelle, 2007a, 2007b), as well as assessment materials (Atkin, 2001).

3.3.1 Challenges of a co-design approach

As with any approach that requires high levels of collaboration between various parties, problems may arise and tensions may build throughout the duration of the project. Rochelle et al. (2006) identify a number of possible issues that can emerge between stakeholders in the co-design process. Most often, these tensions arise when the principles around which the approach is built are neglected or abandoned throughout the research process. For example, stakeholders can come to a design with differing criteria, which can result in conflict in the planning and implementation of design details (Blomberg & Henderson, 1990). Similarly, consultation with teachers is sometimes deferred to the implementation and testing phases, which can cause confusion or disagreements (Cuban, 2001). When such tensions arise, there is also the possibility that the outcome of design efforts may undermine or compromise the values or intentions of the teacher, the researcher, or both—for instance, an innovation does not address research questions directly, or falls short of specific educational aims or requirements. Such complications can arise due to the fact that both researcher and teacher are working within separate constraints and expectations, and these can have a strong and persistent influence on the collaborative dynamic; however, appreciating each other's unique roles and competencies and coming to a mutual understanding can help curb such conflicts and promote productive working relationships

(Roschelle et al., 2006). Negotiating a plan of action that is grounded in pedagogical principles and can satisfactorily meet the objectives and expectations of all parties can be a time-consuming, but necessary, endeavor. Despite these challenges, co-designed research can result in successful, effective and principled educational innovations that are valued by researchers and teachers alike and can become a robust and lasting feature of the classroom.

3.4 Co-Design Team

The co-design team for this thesis research was composed of one Grade 2 classroom teacher, two researchers, including myself and a senior faculty member (thesis supervisor), one assistant researcher and one programmer. Individual roles are described in more detail in the sections below, following a brief description of the study's setting.

3.4.1 Setting

This thesis research was conducted at the Dr. Eric Jackman Institute for Child Study (EJ-ICS) in Toronto (see Appendix A for a description of the school and its admission policies). This school has been using Knowledge Building pedagogy and Knowledge Forum for a number of years, so both the teachers and the students are very familiar both with the pedagogical approach and with the technology. A Knowledge Building ethos is reflected in the school's culture, and is evident in everyday practices including regular in-class activities, the language students and teachers adopt when in the classroom, community-building teacher meetings, as well as other professional development activities. As such, this school represents "optimal conditions" for the proposed research (Fischer & Bidell, 1997).

3.4.2 Researchers and Developers

I began this project after one and a half years of course studies and participation in research at the Institute for Knowledge Innovation and Technology (IKIT), both of which centered on exploring Knowledge Building pedagogy and technology. During the course of this thesis work I also relied on the help of a research assistant, Alisa Acosta, a high school science teacher and OISE M.Ed student who assisted in qualitative coding of student data. I also worked with one developer, Bodong Chen, who is a fellow PhD student at IKIT with expertise in programming. He made refinements to the automated assessment tools when required (for instance, programming the interactivity feature on the Metadiscourse tool). I maintained all contact with both Alisa and Bodong during the course of the study, and co-ordinated communication between the teacher and the rest of the team. Because both Alisa and Bodong were colleagues at IKIT, they were deeply familiar with the research objectives and theoretical frame of this research, which made communication about the research needs and goals very productive.

3.4.3 Teacher

The Grade 2 teacher that participated in this research is an experienced teacher at EJ-ICS who had worked mainly with kindergarten students, and had just moved to teach Grade 2 in 2010 when this research began. This teacher taught each Grade 2 class during the following two years of this study. The teacher and I became acquainted through my involvement with IKIT, which has a close working relationship with the EJ-ICS school. She volunteered that I come and do work in her classroom. As a teacher who had worked at the school for some time before my arrival, she was familiar with the pedagogical approach of Knowledge Building and had used Knowledge Forum for a number of years. From the very beginnings of the project, the teacher was an active and willing participant deeply involved with many aspects of the study, from designing treatment sessions to making suggestions for refinements to improve automated tools used in the classroom.

For this study, the teacher and I maintained continual contact throughout the school year and met approximately twice a month for 30-minute briefings during the regular school year. Frequent meetings helped keep planning consistent and on track, and was necessary to inform next steps for design interventions, such as preparing feedback visuals that corresponded to the themes emerging in student discourse. Bi-weekly teacher meetings attended by the schools' entire staff were also used as opportunities to present research to the wider school community and to engage in group discussions that directly targeted Knowledge Building principles and issues involved in enacting those principles in practice. These whole-school conversations, as well as bi-monthly one-on-one meetings, were invaluable for re-affirming the principles on which the research was based and for maintaining a common goal.

3.4.4 Students

Participants for this study included students and teachers from Grades 1-6 at the Dr. Eric Jackman Institute for Child Study (EJ-ICS) in Toronto. There were three distinct student cohorts involved in this research, corresponding to the three major phases of the project (detailed in Section 3.6 below). Phase I spanned the 2009-2010 and 2010-2011 school years, with students and teachers from five separate classes (Grades 1-6, $n = 102$) participating in the study. Data derived from all classes in this stage of the project represents "benchmark" data, and consists of naturally occurring work by students—that is to say, the classes in question did not participate in any design interventions but carried out their work in accordance to their regular classroom practice. None of these students were exposed to any experimental treatments, nor did any of the teachers participate in co-design processes. Phases II and III represent experimental stages of the research, and include participants from Grade 2 classes in the 2010-2011, 2011-2012, and 2012-

2013 school years (*n* = 62). Of this cohort of students, the 2010-2011 group was not subject to any treatments, so data collected from this class represents a subset of "benchmark" data. However, Both the Grade 2 classes from the 2011-2012 and 2012-2013 include students that were directly involved in Design Cycle 1 and Design Cycle 2 of this research, respectively. Thus, the students from these two consecutive years represent the experimental groups for this research.

3.5 Overview of Research Plan

Below I map out a brief overview of the three phases of this research:

Phase I: This phase of research consisted of in-class observation as well as analysis of online contributions made by students in five classes throughout Grades 1-6, as archived on five distinct Knowledge Forum databases. Guiding questions for this phase include: What types of discursive contributions do young students naturally exhibit when engaged in Knowledge Building practice? What types of contributions are the most common or uncommon in the online discourse? Are contribution patterns evident either within or across grades? What role might certain contribution types play in facilitating group advances in shared knowledge?

Phase II: This phase focuses on identifying contribution types that are infrequent or absent in students naturally occurring explanation-seeking dialogue, as exhibited in the data collected in Phase one, and on providing feedback to students to help them expand the diversity of their discourse. Research also centres on identifying the particular contributor types that enable advancement of group dialogue, and on testing out interventions designed to raise the level of student discourse. Specifically, treatments include the introduction of new scaffolds to boost effective collaboration for knowledge advancement, repeated metadiscourse sessions to promote collective reflective discussion, and the use of the Metadiscourse Tool to facilitate metadiscourse and to provide formative feedback aimed to expand student contribution repertoire.

Phase III: Research in this final phase consists of targeted refinements and interventions that extend year two findings. These include: (a) focus on segments of online dialogue during class discussions to facilitate meta-cognitive reflection (Brown & Campione, 1996); and (b) work with refined feedback designs that target curriculum goals.

3.6 Data Sources and Analytic Approach

Data sources and corresponding research instruments will include:

(a) *In-class observation:* In Phase I, I was present in various classrooms at different times during Knowledge Building sessions to observe classroom work and take field notes. During Phases II and III, I was present for almost every Knowledge Building session in the Grade 2 classes, as well as any other events related to the inquiry units such as field trips or presentations by classroom visitors. Field notes were taken and videos of treatments were recorded consistently during these Phases to provide important contextual information about classroom activities and to supplement student work on the database.

(b) *Content of student generated notes in Knowledge Forum:* Data analysis of student notes was consistent across all three Phases and focused on two main aspects—namely, contribution measures and knowledge advancement measures. The specific coding schemes and tactics used to guide analysis on these two aspects are described here:

i.) Contribution Measures: A coding guide based on the "Ways of Contributing to Explanation-Seeking Discourse" inventory described in detail in Chapter 2, Section 2.5.4, was used to analyze all student notes (see Table 1). This scheme was used for analysis in the studies described in Chapters 4, 5, and 7 and includes six main categories and 24 subcategories. I present the coding guide with a detailed description of the 24 subcategories and related examples in Appendix E.

Table 1

"Ways of Contributing to Explanation-Seeking Discourse" Scheme

Main Category	Subcategory
Formulating thought-provoking questions	1—explanatory questions
	2—design questions
	3—factual questions
2—Theorizing	4—proposing an explanation
	5—supporting an explanation
	6—improving an explanation
	7—seeking an alternative explanation
3—Obtaining Information	8—asking or looking for evidence
	9—testing hypotheses
	10—reporting experimental results
	11—introducing new information (source)
	12—introducing new information (experience)
	13—identifying a design problem
	14—thinking of design improvements
4—Working with Information	15—providing an evidence or reference to support a particular explanation
	16—providing an evidence or reference or to discard a particular explanation
	17—weighing different explanations
	18—accounting for conflicting explanations
5—Synthesizing and Comparing	19—synthesizing available knowledge
	20—making a comparison or analogy
	21—initiating a rise-above entry
6—Supporting Discussion	22—using diagrams to communicate or support ideas
	23—giving an opinion
	24—acting as a mediator

ii.) *Secondary Contribution Measures:* In addition to coding for ways of contributing, secondary analysis was also performed on each note, and traced the following measures: i) total number of notes; ii) total number of contributions; iii) contributor diversity (number of unique contributions engaged per student with respect to the six main categories in the "Ways of Contributing" scheme as well as its 24 subcategories); iv) and contribution richness (number of unique contribution types per single note).

iii) *Knowledge Advancement:* The approach for assessing knowledge advancement described here was also used for the studies described in Chapters 4, 5, and 7. "Theorizing" notes were assessed using two coding schemes designed to measure ""'scientificness'"" (Zhang et al., 2007) and ""'epistemic complexity'"" (Zhang et al., 2009) of ideas. ""'scientificness'"" implies the degree to which an idea is scientifically accurate. The scale to evaluate "scientificness" of student ideas includes the following four levels:

- 1–prescientific, which entails explanations containing a misconception while applying a naive conceptual framework
- 2–hybrid, which includes explanations containing misconceptions that have incorporated scientific information
- 3–basically scientific, which refers to explanations based on a scientific framework, but not precise.
- 4–scientific, which are explanations that are consistent with scientific knowledge.

Second, "epistemic complexity" represents the level of cognitive effort and written sophistication evident in an explanation. For example, stating a scientific fact is easier than articulating an elaborated explanation. The scale for this measure also includes four levels:

- 1–unelaborated facts, or basic statement about terms, phenomena or experiences
- 2– elaborated facts, which include elaboration about terms, phenomena or

experiences

- 3–unelaborated explanations, or statements that includes reasons, relationship or mechanisms
- 4–elaborated explanations, which include elaboration on reasons, relationship or mechanisms for a particular phenomenon

(c) *Metadiscourse Tool:* The Metadiscourse Tool, which is described in detail in Chapter 2, was used to provide feedback to students to help them raise the level of their explanation-seeking dialogue throughout the course of the study.

(d) *KBDex:* This program was used to generate visualizations and to conduct network-structure analyses based on students' online discourse in Knowledge Forum.

(e) *Wordle:* This program was used to generate word cloud visualizations based on students' online discourse in Knowledge Forum.

3.7 Chapter Summary

In this chapter, the central characteristics of design-based research were described, and some challenges associated with the approach were explored. Following this, the main principles of a co-design methodology were outlined, and the integration of this complementary approach within the main design was addressed. The unique challenges that come with a co-design approach were then considered in brief, and the strategies used in this study to mitigate these difficulties were outlined. Discussion then moved to describing the study's setting and the co-design team. Next, an overview of the study's three main phases was outlined. The chapter concluded with a description of the data sources and methods of analyses used throughout the course of the research.

CHAPTER 4: WAYS OF CONTRIBUTING TO EXPLANATION-SEEKING DISCOURSE IN ELEMENTARY SCHOOL: AN OVERVIEW

4.1 Chapter Overview

This chapter reports the results of an initial exploratory study conducted using the "Ways of Contributing" inventory introduced in Chapter 2. The study reports findings from the first phase of this thesis project and explores the contribution makeup of young students' naturally occurring Knowledge Building discourse in science across Grades 1-6. In this study, the contribution repertoire of five different classes are mapped in order to identify the frequency of various contribution types within each group's dialogue, and to determine any possible patterns with respect to contribution makeup both within and across grades. Students' engagement with various ways of contributing is also compared across grade levels to determine whether students' contribution repertoire expand as they advance in school. The level of knowledge advancement achieved by each group is also assessed. Finally, trend analyses are conducted to determine the extent to which these confirm previous analyses. The chapter begins with a description of the methodology used to collect and analyze data, followed by a summary of results and discussion of the findings corresponding to each research question. The chapter concludes with commentary about the implications of the findings to the design of experiments in Phase II of this research.

4.2 Methods and Analyses

Both qualitative and quantitative methods of data analysis are employed in this study. The benefits of a mixed-method approach to educational research are well documented (e.g. Creswell, 2007). A mixed method approach has been employed in similar studies exploring discourse patterns and discussion quality in asynchronous online discourse (Lipponen, Rahikainen, Lallimo, & Hakkarainen, 2001). Because this research explores complex dialogic dynamics—namely, how to boost students' contribution repertoire for engaging in collaborative explanation-seeking discourse, and how increased contributor diversity might impact group knowledge advancement—utilizing a mixed method approach is suitable, as it can illuminate potentially unnoticed aspects of the phenomena under scrutiny, as well as substantiate findings if results emerging from various analyses prove to complement or support one other (Erzberger & Kelle, 2003). A mixed-method approach is also appropriate for design-based research, which is iterative and intended to be transformative in its outcome (Creswell, 2007, p. 17).

As a starting point for the exploration of students' Knowledge Building work in this exploratory study, qualitative content analysis (Chi, 1997) is used to investigate possible patterns or trends relating to students' ways of contributing to explanation-seeking discourse, as well as the extent of their collective knowledge advancement. While a relatively high number of quantitative tests are conducted with a relatively small number of students, the goal was to explore findings from multiple perspectives, with focus on findings consistent across analyses.

4.2.1 Participants

The participants for this study include 102 students (49 boys, 53 girls) from five classes ranging from Grades 1-6 at the Dr. Eric Jackman Institute of Child Study in Toronto.

4.2.2 Dataset

The dataset for this study consists of a total of 1,209 notes as archived on five distinct Knowledge Building databases across Grades 1-6. The work from the Grades 1-4 was produced in the 2009-2010 school year. The work from the Grade 5/6 database was produced in 2010-2011. As a result, seven students (five girls, two boys) have work in two databases. However, since none of these classes was subject to any type of intervention, the data in all classes represents the naturally occurring work of elementary-aged students. All Knowledge Building units were focused on science. The Grade 1 database explores Water and the Water Cycle, and features 370 notes. The Grade 2 database investigates Life Cycles, with a focus on Trees and Forests, and includes 121 notes. The Grade 3 class explored Soil and Fungi, generating a total of 141 notes on their database. The Grade 4 database centres on Rocks and Minerals, and consists of a total of 272 notes. Finally, the Grade 5/6 class worked on Astronomy, generating a sum of 305 notes in their database.

4.2.3 Plan of analysis

Data analysis focused on two main aspects, as introduced in Chapter 3:

i.) *Contribution Measures:* The "Ways of Contributing" coding guide was used to analyze all 1209 student notes (see Table 1). If a note exhibited more than one form of contribution, for example, "asking an explanatory question" and "proposing a theory," that note was coded as displaying two distinct contribution types. Contribution types will be identified throughout the course of this thesis in quotation marks, with main contribution categories capitalized. Two raters coded all databases and achieved a cumulative agreement rate of 95.52% (Grade 1, 99.27%; Grade 2, 98.65%; Grade, 3, 82.5%; Grade 4, 99.57%; Grade 5/6, 97.63%). Secondary analysis was also performed on each note, and includes the following measures: i) total number of notes; ii) total number of contributions; iii) contributor diversity iv) and contribution richness. Secondary contribution measures will likewise be identified by use of quotation marks from this point on.

ii.) *Knowledge Advancement:* To examine community knowledge advancement, the same two raters who coded for "Ways of Contributing" used content-based analysis to select notes from the online discourse that represented "Theorizing" work. Such notes exhibited students' explicit attempts to produce explanations and express original ideas, and as such comprised useful examples of students' productive writing and their ability to convey conceptual understanding. "Theorizing" notes were assessed using two coding schemes designed to measure "scientificness" (Zhang et al., 2007) and "epistemic complexity" (Zhang et al., 2009) of ideas, each comprised of four levels (see Chapter 3, Section 3.6). Similar to contribution measures, quotation marks will be used to identify knowledge advancement items. Overall, agreement for "scientificness" of notes reached 82% and 81.65% for "epistemic complexity" (Grade 1, 76.8% and 80%, Grade 2 100% and 93.34%; Grade 3, 80% and 80%, Grade 4, 70% and 81.82%; Grade 5/6 81.25% and 71.43%. Discrepancies were resolved through discussion.

4.3 Results

Results reported below correspond to four methods of data analysis. First, the contribution repertoire of each class was calculated based on the frequency of use of each type of contribution as identified by the "Ways of Contributing" scheme. Next, findings from Spearman correlation analysis map out the relationships that exist between different contribution types in each respective discourse. A series of one-way ANOVA comparisons are then outlined across the five grades to help determine whether students' contribution repertoire expand across grade level. The same tests were also conducted on knowledge advancement measures in order to determine whether significant differences exist between groups in this area. Finally, a series of trend tests (linear and curvilinear) were conducted to detect significant trends across grades on all measures.

4.3.1 Contribution repertoire: How do elementary-aged students contribute to an explanation-seeking dialogue in science?

Table 2 shows the contribution repertoire of each grade according to the main "Ways of Contributing" categories. Participation with contribution subcategories was also traced in order to acquire a finer-grained look at the types of discourse moves that characterize each classroom's dialogue (see Table 3). Results show that the three most frequently made contribution types corresponding to the scheme's main categories are shared across Grades 1-4 and include "Theorizing," "Questioning," and "Supporting Discussion," in that order.

Table 2

Frequency of Occurrence (n) of Main "Ways of Contributing" Types in Each Group's Online Discourse (M, SD)

	Asking Thought-Provoking Questions	Theorizing	Obtaining Information	Working with Information	Synthesizing and Comparing	Supporting Discussion
Gr 1	5.35 *(4.59)*	9.45 *(7.12)*	1.55 *(1.82)*	0.50 *(0.83)*	0.25 *(0.64)*	2.70 *(3.18)*
Gr 2	1.14 *(0.99)*	4.32 *(2.35)*	0.36 *(0.66)*	0.14 *(2.10)*	0.18 *(0.39)*	0.50 *(0.74)*
Gr 3	1.68 *(2.87)*	3.09 *(3.57)*	1.27 *(1.86)*	1.18 *(1.53)*	0.36 *(0.79)*	1.86 *(1.28)*
Gr 4	4.43 *(3.01)*	6.76 *(5.92)*	2.10 *(2.32)*	0.29 (0.64)	0.10 *(0.03)*	2.19 *(2.14)*
Gr 5/6	5.67 *(3.00)*	7.95 *(6.67)*	3.00 *(5.03)*	1.29 *(3.54)*	0.33 *(0.73)*	1.05 *(1.16)*

Participants (n = 102) * $p < .05$ ** $p < .01$

Looking at the finer-grained subcategories, findings show that in Grades 1 and 2, the three most popular dialogue moves include "asking explanatory questions", "proposing an explanation " and "supporting an explanation"; in Grade 3, the most common ways of contributing are "giving an opinion," "proposing an explanation," and "supporting an explanation"; in Grade 4 the top three types are "proposing an explanation," "asking explanatory questions," and "supporting an explanation." The Grade 5/6 class begins to stray from this pattern, with "Theorizing" and "Questioning" remaining the two most frequently contributed discourse moves, followed up by "Obtaining Information." More specifically, in Grade 5/6, the most popular ways of contribution include "proposing an explanation," "asking factual questions," and "introducing a new fact from a source." In general, findings illustrate that, within

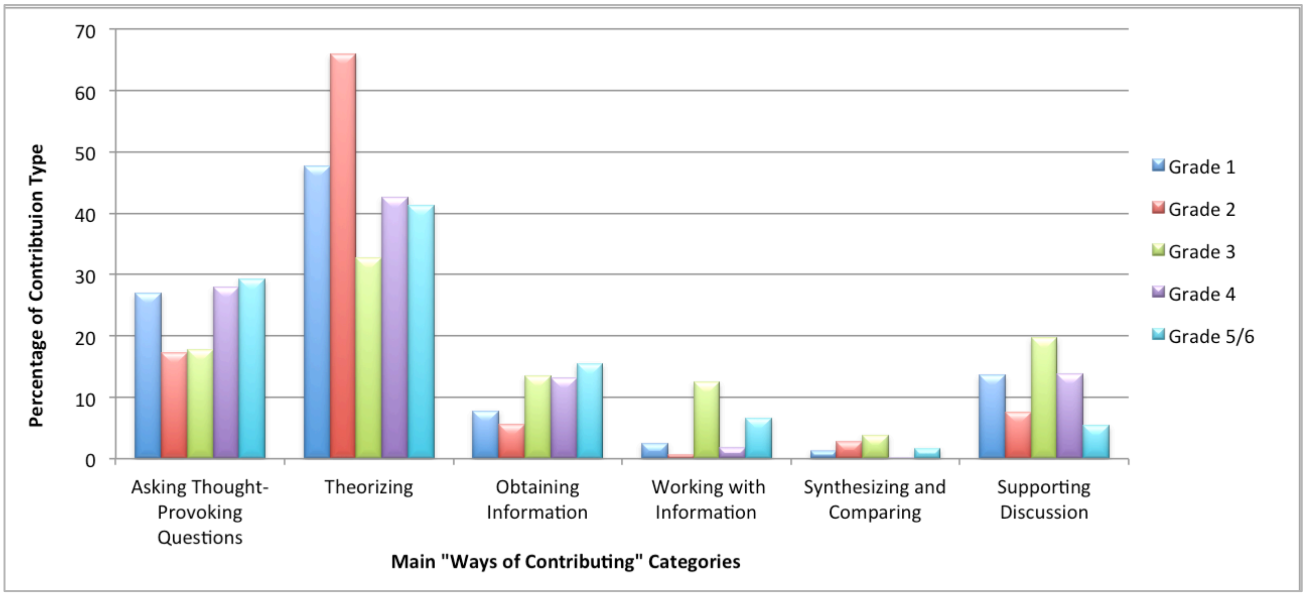

Figure 4. Percentages of "Ways of Contributing" types as exhibited in each group's online discourse across Gr. 1-6.

Grades 1-4, students' discourse is dedicated to a large extent on posing their own questions and theories, and to supporting their own ideas by giving plausible reasons and justifications. It is only in Gr 5/6 that the discourse begins to exhibit a higher proportion of discussion around factual, authoritative knowledge.

In terms of the most infrequently made contribution types, both "Working with Information" and "Synthesizing and Comparing" appear the least in students' discourse across all grades. Looking more closely at each grade, the most infrequent contribution types in Grades 1, 3 and 4, in descending order, include "Obtaining Information," "Working with Information," and "Synthesizing and Comparing". In Grade 2, this pattern is only slightly different, with contributions to "Working with Information" slightly lower than "Synthesizing and Comparing." Furthermore, as Table 3 on the following page shows, a number of contribution subtypes that correspond to these main categories remain low or absent altogether in primary students' discourse. These include contribution subtypes such as "reporting experimental results," "testing hypotheses," "weighing different ideas," "accounting for conflicting explanations," "initiating a rise-above entry," among others.

In Grade 5/6, the least common contribution types are different from those in Grades 1-4. The three most infrequent contribution types, in descending order, include "Working with Information," "Supporting Discussion" and, last, "Synthesizing and Comparing". However, the contribution subtypes that the Grade 5/6 students rarely engage or do not contribute at all are almost identical to those identified for Grades 1-4, and include: "reporting experimental results," "testing hypothesis," "identifying a design problem,", "improving a design problem," "accounting for conflicting explanations," and "initiating a rise-above entry."

As these results show, a number of contribution types are particularly challenging for young students at the elementary level to engage without extra support. The fact that "Synthesizing and Comparing" represents the most rarely made contribution category is not particularly surprising. This is because this contribution category represents some of most difficult processes involved in knowledge building dialogue, such as "initiating a rise-above entry." Furthermore, this contribution category also includes dialogue moves that themselves require a considerable amount of preceding work, such as "synthesizing available knowledge." That is, students need to introduce a range of theories and facts before being able to synthesize available knowledge or formulate higher-level conceptualizations. Findings from previous studies corroborate these results and show that syntheses and rise-above are lacking in many samples of student work (Scardamalia & Bereiter, 2006; van Aalst, 2009). However, the importance of continual movement from divergence to convergence of ideas and information is essential to the advancement of the discourse in knowledge creation work, and so the low

Table 3

Frequency (n) of Occurrence of "Ways of Contributing" Subtypes in Each Group's Online Discourse (M, SD)

	Explanatory Questions	**Design Questions**	**Factual Questions**	**Proposing an Explanation**	**Supporting an Explanation**	**Improving an Explanation**
Gr. 1	4.45 *(4.31)*	0 *(0.00)*	0.90 *(1.21)*	3.65 *(3.25)*	2.75 *(2.34)*	1.30 *(1.56)*
Gr 2	1.05 *(1.00)*	0 *(0.00)*	0.09 *(0.29)*	2.09 *(1.90)*	1.36 *(1.00)*	0.32 *(0.57)*
Gr 3	0.82 *(1.05)*	0 *(0.00)*	0.86 *(2.05)*	1.05 *(1.33)*	1.00 *(1.57)*	0.55 *(1.01)*
Gr 4	2.67 *(2.18)*	0.10 *(0.30)*	1.67 *(1.35)*	3.29 *(3.24)*	2.24 *(2.32)*	0.62 *(0.92)*
Gr 5/6	2.62 *(2.04)*	0.05 *(0.22)*	3.00 *(2.19)*	4.24 *(3.10)*	2.19 *(2.16)*	0.67 *(1.59)*

	Seeking an Alternative Theory	**Asking for Evidence**	**Reporting Experimental Results**	**Testing Hypotheses**	**Introducing New Information (Source)**	**Introducing New Information (Experience)**
Gr. 1	1.75 (1.92)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.85 (1.23)	0.70 (1.13)
Gr 2	0.55 (0.51)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.23 (0.43)	0.14 (0.47)
Gr 3	0.50 (0.91)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.64 (1.14)	0.64 (0.90)
Gr 4	0.62 (0.97)	0.29 (0.72)	0.00 (0.00)	0.00 (0.00)	1.47 (2.27)	0.33 (0.58)
Gr 5/6	0.86 (1.01)	0.10 (0.30)	0.00 (0.00)	0.00 (0.00)	2.76 (4.90)	0.14 (0.36)

	Identifying a Design Problem	**Improving a Design Problem**	**Support Expl. with Evidence**	**Discarding Exp. with Evidence**	**Weighing Explanations**	**Accounting for Conflicting Explanations**
Gr. 1	0.00 (0.00)	0.00 (0.00)	0.35 (0.75)	0.15 (0.49)	0.00 (0.00)	0.00 (0.00)
Gr 2	0.00 (0.00)	0.00 (0.00)	0.05 (0.21)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Gr 3	0.00 (0.00)	0.00 (0.00)	0.73 (1.24)	0.45 (0.91)	0.00 (0.00)	0.00 (0.00)
Gr 4	0.00 (0.00)	0.00 (0.00)	0.29 (0.64)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Gr 5/6	0.00 (0.00)	0.00 (0.00)	0.95 (3.06)	0.19 (0.51)	0.14 (0.48)	0.00 (0.00)

	Synthesizing Available Knowledge	**Making Comparisons or Analogies**	**Initiating a Rise-above Entry**	**Communicating Ideas Through a Diagram**	**Giving an Opinion**	**Acting as a Mediator**
Gr. 1	0.05 (0.22)	0.20 (0.52)	0.00 (0.00)	0.00 (0.00)	2.45 (2.63)	0.25 (0.64)
Gr 2	0.05 (0.21)	0.14 (0.35)	0.00 (0.00)	0.00 (0.00)	0.45 (0.60)	0.05 (0.21)
Gr 3	0.00 (0.00)	0.36 (0.79)	0.00 (0.00)	0.00 (0.00)	1.82 (1.33)	0.05 (0.21)
Gr 4	0.05 (0.22)	0.00 (0.00)	0.05 (0.22)	0.05 (0.22)	1.71 (1.71)	0.43 (0.68)
Gr 5/6	0.10 (0.44)	0.24 (0.44)	0.00 (0.00)	0.10 (0.30)	0.52 (0.68)	0.43 (0.81)

Participants (n = 102) * $p < .05$ ** $p < .01$

percentage of dialogue dedicated to this discursive category reported here, ranging from less than 1% to not quite 4% of a group's total discourse across grade levels (see Table 3), indicates that students could benefit from increased support in this area. Furthermore, the extremely rare or altogether absent engagement of certain contribution subcategories that fall under "Obtaining Information" and "Working with Information" suggest that, while some dialogue moves corresponding to these categories are easier for students to make without explicit support, expanding their repertoire requires that students develop more sophisticated capacities in these areas. This can include expanding the sources from which they gather and then report information, engaging more deeply with designing and refining experiments, working to corroborate seemingly disparate information and facts, and synthesizing ideas in the interest of continually advancing the frontiers of community knowledge.

Overall, the average contribution level of each dialogue move (see Figure 5) show that contribution profiles remain fairly consistent in each of the primary years (Gr. 1-3) and into the first junior year (Gr. 4), with contribution repertoire only beginning to change in any significant way in the later junior years (Gr. 5/6). One explanation for this pattern could be that primary grade children are natural and particularly persistent question-askers, and, being less constrained by authoritative or scientific knowledge, are also quite imaginative in their theorizing. Thus, primary students are quite capable of generating a high number of scientific questions as well as a diversity of original ideas and theories in their naturally occurring Knowledge Building dialogue. While the profiles for the contribution makeup remain highly consistent across Gr. 1-4, a change becomes evident in Grade 5/6, with a higher proportion of the discourse dedicated to posing factual questions and working with factual knowledge. This shift could be due to a number of interconnected reasons, including the more frequent use of external sources in the older grades, or the tendency of junior grade students to rely on or turn to official or authoritative sources of information to help provide answers to their questions. Further work in this area

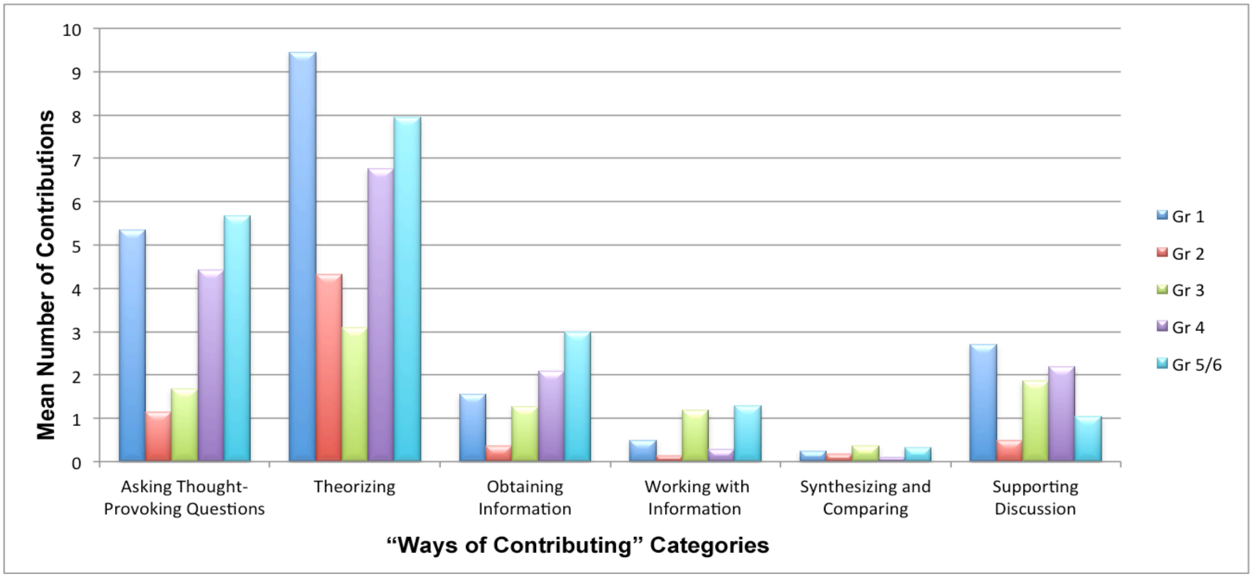

Figure 5. Contribution profiles: Average number of contributions for main "Ways of Contributing" types as exhibited in each group's online discourse Gr. 1-6.

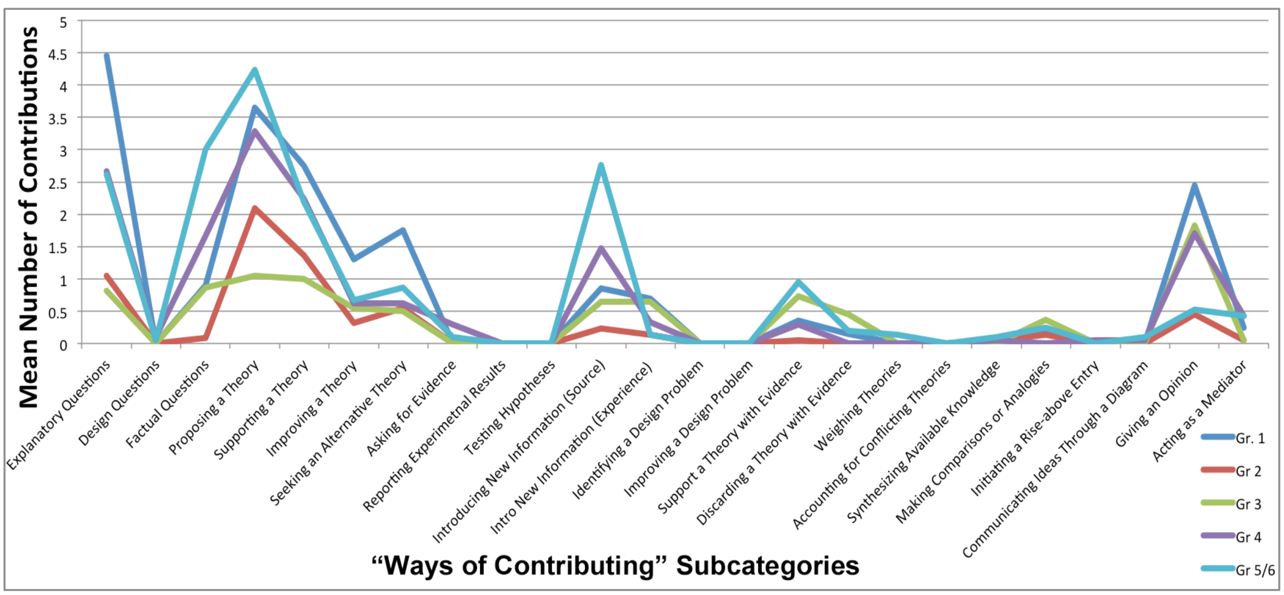

Figure 6. Contribution profiles: Average number of contributions for "Ways of Contributing" subtypes as exhibited in each group's online discourse Gr. 1-6.

would need to be done in order to determine possible causes for this discursive shift and whether it reflects a more stable developmental pattern that extends beyond the study participants. For the purposes of this research, it is enough to identify the general profiles in order to select infrequent or rare discourse moves that might require further support. To this end, the results reported here indicate that a number of discourse types represent particular challenges for elementary students. For Grades 1-4, the contribution types within the categories of “Obtaining Information,” “Working with Information,” and “Synthesizing and Comparing” represent categories of contribution types that could be targeted for pedagogical and technological interventions designed to boost their presence in the discourse, with the latter two categories also representing discourse moves that might be selected for this type of work in Grade 5/6.

4.3.2 Correlations: Are there relationships between various contribution types?

In order to explore any significant relationships between contribution types both within and across grades, Spearman correlation analysis was conducted on each group’s discourse. This analysis was performed at both the main category and subcategory levels, and was also conducted on secondary contribution measures. Findings corresponding to each item are displayed in Table 4 and are elaborated here:

i) *Main categories*: Findings from analysis interrogating the main “Ways of Contributing” categories show various positive correlations, which are summarized in Table 4 on the following page. Some general comments can be made regarding patterns observable across all groups. For instance, “Obtaining Information” and “Working with Information” are significantly correlated across Grades 1, 3, and 5/6, indicating that primary and junior students are actively working to integrate established facts and information with their own ideas and theories. That “Theorizing” and “Obtaining Information” were positively correlated in both primary (Grade 1) and junior (Grade 4) classes, suggests that Knowledge Building students across this developmental range are capable of using sources productively in their scientific inquiry by utilizing authoritative information in ways that influence other important contribution types. This is important to note because, as these results suggests, young students are able to fruitfully introduce authoritative

Table 4

Correlations (Spearman's r and p) for Main "Ways of Contributing" Types

Grade 1	**1**	**2**	**3**	**4**	**5**	**6**
1	1.00					
2	0.40	1.00				
3	0.15	0.63**	1.00			
4	0.32	.724**	0.56*	1.00		
5	-0.13	0.423	0.43	0.20	1.00	
6	0.24	0.216	0.42	-0.06	0.18	1.00
Grade 2	**1**	**2**	**3**	**4**	**5**	**6**
1	1.00					
2	-0.25	1.00				
3	-0.20	0.33	1.00			
4	-0.02	0.26	0.44*	-		
5	-0.05	-0.09	0.26	-	1.00	
6	-0.23	0.44*	-0.15	-	-0.39	1.00
Grade 3	**1**	**2**	**3**	**4**	**5**	**6**
1	1.00					
2	0.17	1.00				
3	0.339	0.20	1.00			
4	0.54**	0.32	.54**	1.00		
5	0.10	.54**	0.09	-0.01	1.00	
6	0.35	0.42	0.09	0.14	0.39	1.00
Grade 4	**1**	**2**	**3**	**4**	**5**	**6**
1	1.00					
2	0.01	1.00				
3	-0.25	.51*	1.00			
4	0.03	.53*	0.23	1.00		
5	0.07	0.08	0.21	-	1.00	
6	0.02	0.25	0.15	-	-	1.00
Grade 5/6	**1**	**2**	**3**	**4**	**5**	**6**
1	1.00					
2	0.56**	1.00				
3	0.40	0.38	1.00			
4	0.06	0.31	.543*	1.00		
5	-0.26	-0.06	0.34	0.44*	1.00	
6	0.30	.601**	0.09	0.38	-0.01	1.00

Numbers correspond to the following contribution types: 1—Asking thought-provoking questions, 2—Theorizing, 3—Obtaining information, 4—Working with information, 5—Synthesizing and comparing, 6—Supporting discussion.

Participants (n = 102) * $p < .05$ ** $p < .01$

sources into collaborative discussion in ways that do not stifle or halt the contribution of their own ideas, as can sometimes occur when information from authoritative sources is accepted uncritically or perceived as beyond question in group discourse (van Aalst, 2009).

Similarly, results show that at all grade levels, the more students are introducing new facts into the dialogue, and the more they are also attempting to put these facts to work in the interest of generating increasingly coherent scientific explanations. In other words, students are not simply introducing isolated facts into the discourse, but are productively engaging with information in efforts at supporting, rejecting, or corroborating available ideas and improving their own explanations. Moreover, "Synthesizing and Comparing" was positively correlated to "Theorizing" in Grades 2 and 3 and with "Working with Information" in Grade 5/6. This suggests that important elements of scientific inquiry, such as actively contributing original ideas and constructively working with facts and information, are important for promoting higher-order thinking in students. Last, analysis reveals that as students get older, the more their contributions might influence one another. For example, the more Grade 5/6 students participate in "Obtaining Information," the more they are likely to also be "Working with Information," as well as "Synthesizing and Comparing" available information and ideas. These findings show that contribution types appear to feed off of each other to a greater degree as students grow in their capacity to engage in explanation-seeking discourse.

ii) *Subcategories:* Findings from Spearman's correlation analysis of the twenty-four "Ways of Contributing" subcategories (see Chapter 3, Section 3.6) show a high number of significant positive correlations between various contribution types. Because of the volume of significant correlations that emerge as a result of analysis, I elaborate briefly on a few notable points of interest. With respect to overall contribution patterns across grades, there appears to be an increase in the number of contribution types that are positively correlated to each other as the grade levels progress. For instance, while the Grade 2 class exhibited two significant correlations between contribution subtypes, the Grade 3 class showed six positive correlations, the Grade 4 students demonstrated 13, and the Grade 5/6 class exhibited a total of 18. This suggests that, as students get older, a wider variety of contribution types are more positively bound up together and help students to build and advance their explanation-seeking dialogue. However, results also indicate that grade level is not necessarily the dominant determining factor for the degree to which different contribution types can support each other in statistically significant ways, since the youngest of these classes, the Grade 1 class, demonstrated a total of 19 significant correlations in their discourse. Further analysis reported in subsequent sections of this chapter helps to shed light on this unexpected outcome.

iii) *Secondary Contribution Measures:* As shown in Table 5 on the next page, the higher the number of contributions students made, the more diverse their discourse; this stood to be the case in all groups. Only in the Grade 5/6 class was this not the case with respect to the main "Ways of Contributing" categories, suggesting that for these older students, making more contributions did not necessarily mean these contributions were spread across the six major contribution types. This finding is not particularly alarming, since the more Grade 5/6 students contributed to their shared discourse, the more these contributions were diversified across all the scheme's 24 finer-grained subcategories. In fact, the positive correlation between total contributions and contributor diversity on the subcategory level was consistently extremely strong in all five groups. This finding is important to note because it suggests that Knowledge Building classes exhibit a dynamic and diverse discourse even at the earliest grade level, and that expanding elementary students' repertoire might be enhanced not by assigning various roles to students during scientific inquiry, but by encouraging increased participation in the general discourse.

With respect to the remaining secondary contribution measures, "richness" correlated to

Table 5

Correlations (Spearman's r and p) for Secondary Contribution Measures

Grade 1	Total Notes	Total Contributions	Contributor Diversity (main)	Contributor Diversity (sub)	Richness
Total Notes	1.00				
Total Contributions	0.99**	1.00			
Contributor Diversity (main)	0.77**	0.79**	1.00		
Contributor Diversity (sub)	0.88**	0.89**	0.94**	1.00	
Richness	-0.18	-0.18	0.06	-0.01	1.00
Grade 2					
Total Notes	1.00				
Total Contributions	.95**	1.00			
Contributor Diversity (main)	0.41	0.61**	1.00		
Contributor Diversity (sub)	0.67**	0.81**	0.83**	1.00	
Richness	-0.29	-0.03	0.51*	0.26	1.00
Grade 3					
Total Notes	1.00				
Total Contributions	0.96***	1.00			
Contributor Diversity (main)	0.63**	0.72**	1.00		
Contributor Diversity (sub)	0.80**	0.82**	0.92**	1.00	
Richness	-0.06*	0.18	0.51*	0.49*	1.00
Grade 4					
Total Notes	1.00				
Total Contributions	0.98**	1.00			
Contributor Diversity (main)	0.48*	0.59**	1.00		
Contributor Diversity (sub)	0.70**	0.79**	0.77**	1.00	
Richness	-0.21	-0.05	0.43	0.23	1.00
Grade 5/6					
Total Notes	1.00				
Total Contributions	0.91**	1.00			
Contributor Diversity (main)	0.30	0.43	1.00		
Contributor Diversity (sub)	0.65**	0.74**	0.77**	1.00	
Richness	0.16	0.42	0.55**	0.60**	1.00

Participants (n = 102) * $p < .05$ ** $p < .01$

"contributor diversity" in the main categories in all classes but Grade 1; also, "richness" related to "contributor diversity" with respect to the subcategories in all classes but Grades 1 and 4. These results suggest that students in Grades 2,3, and 5/6 who made a highly diverse set of contributions were also more likely to make notes that featured more than one contribution type. In the Grade 1 class, children were less likely to write longer notes and seemed instead to write individual contributions on separate notes. This seems plausible as Grade 1 students are just learning how to type and are only beginning to develop skills in typing and writing. As for the Grade 4 students, they were more likely to make two or more contributions that fell under the same category in one note (e.g. "asking an explanatory question" and "asking a factual question"), rather than make contributions of two entirely different types in single entry (e.g. "asking an explanatory question" and "proposing an explanation"). However, the means for "richness" never increases past 1.45 contributions per note in any group (see Table 6), suggesting that students at the elementary school level tend to write shorter notes with only a one or two contribution types per entry. Although addressing possible reasons for this phenomenon is beyond the scope of this study, exploring the wider impact of this trend and the potential benefits and drawbacks it may have on the general discourse would be an intriguing area for further work.

4.3.3 Cross-grade comparisons: Do students contribute differently as they advance in grade? Do their ways of contributing expand with age?

In order to explore any significant differences between engagement with each contribution type in both main and subcategories across groups, a one-way ANOVA was performed on each "Ways of Contribution" category. These were followed up by post-hoc tests (Tukey HSD) to reveal specific attributes of comparisons.

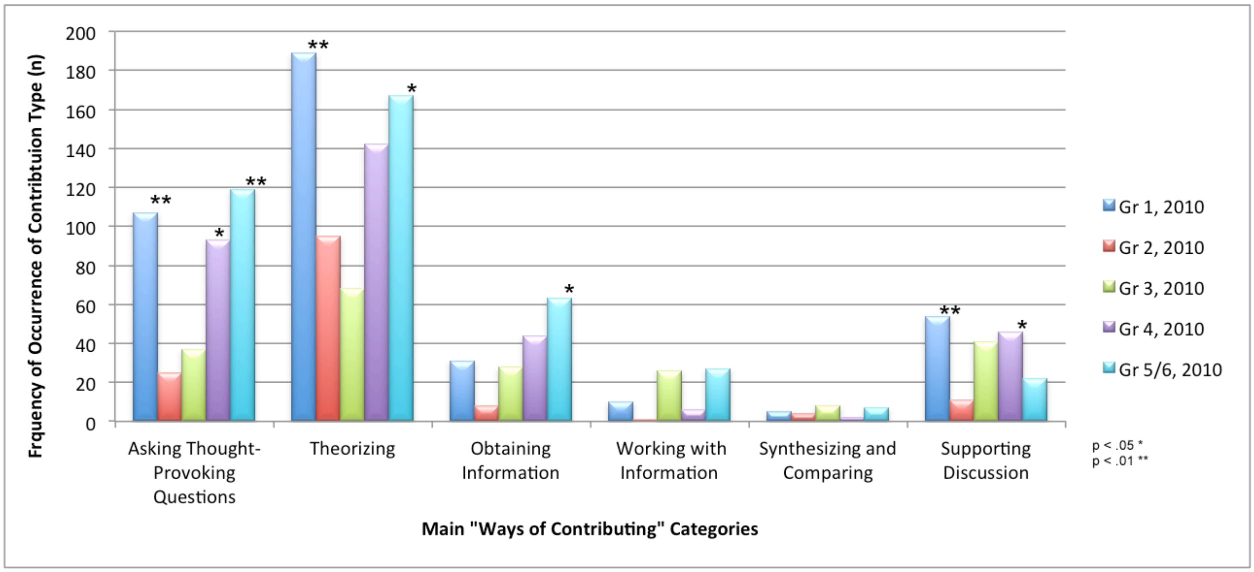

Figure 7. Significant differences in online contribution repertoire (*n*) of main "Ways of Contributing" types as exhibited in each group's online discourse Gr. 1-6.

To begin, findings of comparisons show a significant difference across groups with respect to "Asking Thought-Provoking Questions," $F(4,101) = 9.18$, $p < .0001$. Post-hoc tests show that the Grade 1 class was asking significantly more questions than their peers in Grade 2 ($p < .01$, Cohen's $d = 3.17$) and Grade 3 ($p < .01$, Cohen's $d = 3.17$); similarly, the Grade 4 and 5 classes engaged in more questioning than the Grade 2 class ($p < .01$, Cohen's $d = 3.17$); the Grade 4 students also outperformed the Grade 3 class ($p < .05$, Cohen's $d = 2.63$) on this measure; and finally, the Grade 5 students were asking more questions than the students in the Grade 3 class ($p < .01$, Cohen's $d = 3.17$). Significant differences were found across the two corresponding subtypes of questioning $F(4, 101) = 7.92$, $p < .0001$. For instance, it was found that the Grade 1 class asked significantly more "explanatory questions" than their peers in Grades 2 and 3 ($p < .01$, Cohen's $d = 2.46$). Alternately, there was a significant difference with respect to "factual questions" $F(4,101) = 10.75$, $p < .0001$, with the Grade 5 class asking more fact-based questions than the Grade 1 ($p < .01$, Cohen's $d = 1.62$), Grade 2, ($p < .01$, Cohen's $d = 1.62$) and Grade 3 classes ($p <.01$, Cohen's $d = 1.62$). In addition, the Grade 4 class outperformed the Grade 2 students ($p < .05$, Cohen's $d = 1.35$) on this measure.

With respect to differences in "Theorizing," analysis also revealed significant differences across grades $F(4, 101)= 4.93$, $p < .01$. More specifically, the Grade 1 class did significantly more theorizing work than their primary peers in Grades 2 ($p < .05$, Cohen's $d = 4.61$) and Grade 3 ($p < .01$, Cohen's $d = 5.55$), while the Grade 5 class engaged in theorizing significantly more than the Grade 3 class ($p < .05$, Cohen's $d = 4.61$). Also, analysis on subcategories for "Theorizing" revealed a significant difference for "proposing an explanation" $F(4, 101) = 5.00$, $p < .01$, showing that the Grade 1 students ($p < .05$, Cohen's $d = 2.27$) and the Grade 5 students ($p < .01$, Cohen's $d = 2.74$) were engaging in this contribution subtype significantly more than the Grade 3 class. Furthermore, a difference in "supporting an explanation" was found $F(4, 101) = 2.86$, $p < .05$, with the Grade 1 class outperforming the Grade 3 class ($p < .05$, Cohen's $d = 1.65$) on this measure. Finally, differences with respect to "seeking an alternative explanation" were found to be significant $F(4, 101) = 4.21$ $p < .01$, with the Grade 1 students outperforming the Grade 2, 3, and 4 classes in this area ($p < .05$, Cohen's $d = 0.99$).

Regarding "Obtaining Information," a significant difference was found in terms of performance in this contribution category $F(4, 101) = 2.74$, $p < .05$, with the Grade 5 class outperforming the Grade 2 class ($p < .05$, Cohen's $d = 2.34$). More particularly, the Grade 5 students contributed significantly more than the Grade 2 class ($p < .05$, Cohen's $d = 2.17$) on "introducing a new fact from a source" $F(4, 101) = 3.21$, $p < .05$.

No significant differences were found for "Working with Information" in general, although a significant difference was found $F(4, 103) = 2.81$ ($p < .05$) for "discarding an explanation with evidence," with the Grade 3 class outperforming the Grade 2 class ($p < .05$, Cohen's $d = 0.44$) and the Grade 4 students ($p < .05$, Cohen's $d = 0.44$) on this measure.

Last, significant differences were found for "Supporting Discussion" $F(4, 101) = 4.23$, $p < .01$, with the Grade 1 class engaging in this contribution type more than the Grade 2 class ($p < .01$, Cohen's $d = 1.66$), and the Grade 5 students ($p < .05$, Cohen's $d = 1.61$), respectively; the Grade 4 also outperformed the Grade 2 class ($p < .05$, Cohen's $d = 2.00$) on this measure. In terms of particular types of support, significant differences were found for "giving an opinion" $F(4, 101) = 6.00$, $p < .0001$, with the Grade 1 class making this type of contribution significantly more than the Grade 2 students ($p < .01$, Cohen's $d = 1.65$) and the Grade 5 students ($p < .01$, Cohen's $d = 1.65$). Similarly, the Grade 3 class offered significantly more opinions in their dialogue than the Grade 2 class ($p < .05$, Cohen's $d = 1.33$). No significant differences were found for "Synthesizing and Comparing" among the five groups.

The results of these tests reveal a number of notable outcomes. For example, it appears that the older students get, the more factual questions they ask. Moreover, growth in "asking factual questions" appears to rise concurrently with "Obtaining Information," supporting the notion suggested in the above section that, as students get older, they tend to seek out information from authoritative sources more often in their Knowledge Building work. However, although the Grade 5/6 students engaged significantly more with facts and factual questions than the Grade 2 and 3 students, no significant difference was found between this older class and the Grade 1 group. This finding raises the notion that contribution patterns are not necessarily determined by developmental factors alone but that other factors, such as classroom atmosphere for instance, can have a significant impact on students' capacities to engage in the various ways of contributing that are inherent in and crucial to knowledge building discourse. This observation is significant as it indicates potential space for pedagogical and technological innovations to play an important role in boosting students' competencies for contributing to explanation-seeking dialogue, and thus to working creatively with knowledge beyond that which has been shown by past research in the area.

Similarly, examining performances with respect to “Theorizing” reinforces the notion that despite the age gap, the Grade 1 students in this study represent a very high-functioning group who repeatedly perform on par or outperform the older students with respect to their engagement in various contributor roles. For example, findings shows that students across all groups are capable of engaging in high levels of “Theorizing”; however, the Grade 1students outperform the Grade 3 class with respect to “proposing an explanation,” and also outperform their primary peers, as well as the Grade 4 class, on “seeking an alternative explanation.” This finding suggests that young students are very capable of generating a high number of diverse ideas to their own problems of understanding. This outcome also lends further support to the notion that classroom culture plays a significant role in providing opportunities for students to productively engage in a number of contributor roles important to Knowledge Building discourse. That these same Grade 1 students participated significantly more in “Supporting Discussion,” and more specifically in “giving an opinion” than the Grade 2 and 5 students, and to the same extent as the Grade 3 and 4 classes, suggests that, while younger students are more likely to contribute personal preferences or beliefs into their discussion, this does not necessarily detract from active engagement in other contribution types or negatively impact the health of the discourse as a whole. van Aalst (2009) found that groups that maintain a cohesive sense of community, as exhibited by social commentary in their online discourse, exhibit a more productive discourse than those that do not. Indeed, while the Grade 1 class exhibited a greater degree of their discourse to supportive roles than other classes, they also exhibited the highest proportion of their Knowledge Building work (though not to a significant degree) in “improving an explanation” (see Table 3) than any other grade.

4.3.4 Cross-grade comparisons: Secondary contribution measures

Secondary contribution measures were also tested in order to determine whether there were any significant differences across groups with respect to total number of notes, total number of contributions, contributor diversity, and contribution richness. Results showed significant differences on the following measures: Total notes written $F(4, 101) = 8.70$, ($p < .0001$); contributor diversity with respect to main "Ways of Contributing" categories $F(4, 101) = 3.47$, $p < .05$; contributor diversity regarding "Ways of Contributing" subcategories $F(4, 101) = 3.86$, $p < .01$; and total contributions $F(4, 101) = 5.54$, $p < .0001$. No significant differences were found for contribution richness.

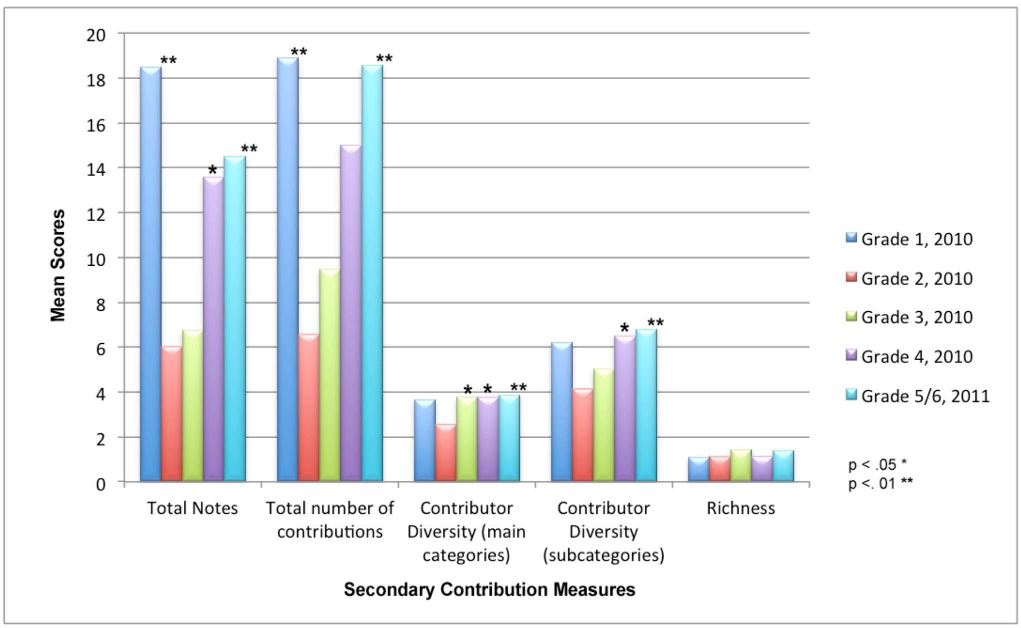

Figure 8. Means (*n*) for secondary contribution measures in each group's online discourse across Gr. 1-6.

Post-hoc tests (Tukey HSD) revealed the following findings: The Grade 1 class wrote significantly more notes than the Grade 2 ($p < .01$, Cohen's $d = 8.58$) and Grade 3 classes ($p < .01$, Cohen's $d = 8.58$); the Grade 4 class outperformed the Grade 2 class with respect to total notes written ($p < .05$, Cohen's $d = 7.11$); the Grade 5 class wrote significantly more than the

Grade 2, Grade 3 and Grade 4 students ($p < .05$, Cohen's $d = 7.11$). In regard to contributor diversity, the Grade 2 students were outperformed by the Grade 3 ($p < .05$, Cohen's $d = 1.02$), Grade 4 ($p < .05$, Cohen's $d = 1.02$) and Grade 5 classes ($p < .01$, Cohen's $d = 1.22$) on the main category measure. On the subcategory level, the Grade 4 (p = <. 05, Cohen's $d = 2.17$) and Grade 5 classes ($p < .01$, Cohen's d = 2.17) contributed more diversely than the Grade 2 class. With respect to "total contributions," the last of the secondary contribution measures, the Grade 1 class made significantly more contributions in total than their peers in Grade 2 ($p < .01$ Cohen's $d = 11.39$), and the Grade 5 class contributed more in total than the Grades 2 students ($p < .01$ Cohen's $d = 11.39$) and the Grade 3 students ($p < .05$, Cohen's $d = 9.45$).

Results for comparisons on secondary contribution measures bear resemblance to differences across grades on ways of contributing items—namely, the tendency for the Grade 1 class to sometimes outperform their primary peers, as well as perform on equal measure with junior level students on a number of measures. For example, the Grade 1 students do just as well

Table 6

Frequency (n) of Occurrence of Secondary Contribution Types in Each Group's Online Discourse (M, SD)

	# of Notes	Total number of contributions	Contributor Diversity (main categories)	Contributor Diversity (subcategories)	Richness
Gr 1	18.50 *(12.39)*	18.9 *(12.69)*	3.65 *(1.27)*	6.20 *(2.88)*	1.09 *(0.15)*
Gr 2	6.05 *(2.82)*	6.60 *(2.96)*	2.55 *(0.91)*	4.14 *(1.36)*	1.13 *(0.32)*
Gr 3	6.67 *(5.73)*	9.48 *(8.66)*	3.77 *(1.52)*	5.05 *(2.68)*	1.45 *(0.58)*
Gr 4	13.60 *(7.83)*	15.00 *(8.90)*	3.76 *(0.88)*	6.52 *(2.32)*	1.14 *(0.13)*
Gr 5/6	13.95 *(9.18)*	18.55 *(16.42)*	3.86 *(1.15)*	6.81 *(2.84)*	1.41 *(0.75)*

Participants ($n = 102$)

as the Grade 4 and 5/6 students by way of writing notes and making contributions in total, as all three of these groups outperform the remaining primary grades on these measures. That no significant difference exists with respect to contributor diversity at either level (main or subcategory) between the junior grade classes and the Grade 1 class suggests that these young primary level students were not only contributing at similar rates but were also contributing just as diversely as their older counterparts.

4.3.5 Cross-grade comparisons: To what extent does depth of understanding correspond to contribution diversity?

While contribution measures do not appear to directly follow a developmental trajectory, analysis for depth of understanding shows a developmental trend. For example, Table 7 shows the mean scores of "scientificness" for each class, which increase steadily from Grade 1 to Grade 5/6. Mean scores for "epistemic complexity" also follow this general pattern, showing only a slight difference between the Grade 2 and the Grade 3 classes.

Table 7

Knowledge Advancement Scores Derived from Online "Theorizing" Contributions (M, SD)

	"scientificness"	"epistemic complexity"
Gr 1	1.55 *(0.33)*	1.68 *(0.40)*
Gr 2	1.82 *(0.61)*	1.79 *(0.62)*
Gr 3	1.77 *(0.79)*	1.77 *(0.56)*
Gr 4	2.25 *(0.50)*	1.94 *(0.66)*
Gr 5/6	2.42 *(0.58)*	2.08 *(0.71)*

Participants (n = 97)

In order to determine any significant differences on these measures, a one-way ANOVA was performed for each. A significant difference was found for "scientificness" across groups $F(4, 97)=7.28$ $p < .0001$. Post-hoc tests (Tukey HSD) reveal that the Grade 4 and 5/6 classes posed more scientifically accurate theories than the Grade 1 class ($p < .01$, Cohen's $d = 0.62$). Similarly, the Grade 5/6 students also outperformed the Grade 2 and 3 classes ($p < .05$, Cohen's $d = .51$) on this measure. Analysis revealed no significant differences across groups for "epistemic complexity."

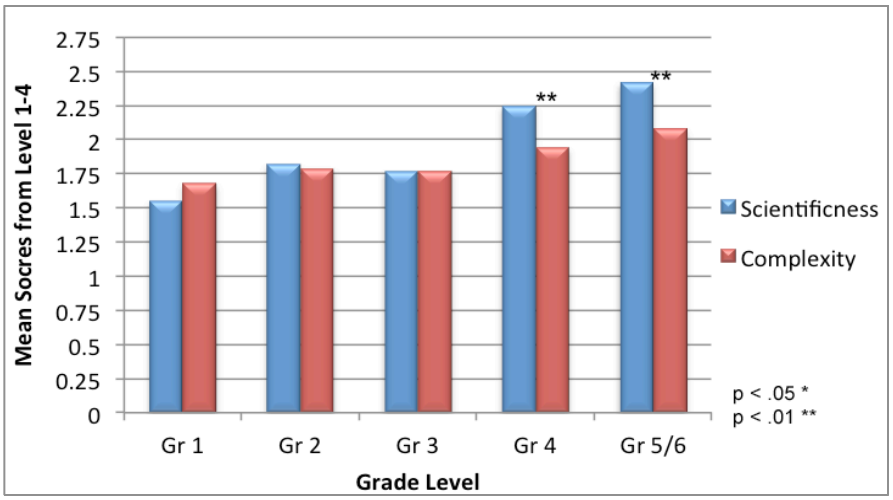

Figure 9. Means (*n*) for knowledge advancement scores from Gr. 1-6.

These results challenge one main hypothesis of this research, which postulates that the more diversely students engage in explanation-seeking discourse, the greater their knowledge advancement, as evident in their discourse. Given their impressive performance with respect to the various contribution measures, why then, does the Grade 1 class not exhibit higher knowledge advancement scores than their primary peers? According to the assessment scheme used to evaluate student work, "scientificness" reflects a growth in domain knowledge, and the gradual change of misconceptions to a scientifically accurate understanding of a certain concept or phenomenon. One explanation could be that the discourse of Grade 1 students remains at a more scientifically naïve level, given that, as the youngest out of the five classes, these students are likely the most "knowledge poor" when it comes to scientific information (Bereiter, 2009). As suggested by correlation analysis, what appeared to help the Grade 1 class improve their theories was the generation of reasons and justifications to support existing theories (see Table 5). On the other hand, with respect to the junior grades, the more students worked with authoritative sources and introduced new facts into the discourse, the greater the chance for theory improvement. So, it seems as though theories and ideas posed by the students in the higher grade levels reflected authoritative knowledge to a greater extent than the Grade 1 class, who did less work with outside sources.

4.3.6 Trend Analyses

As findings reported in previous sections show, students appear to follow a developmental trend for some measures, such as "scientificness" and "epistemic complexity" (see Figure 9), but not for others, such as "asking explanatory questions" or total contributions (see Figures 5, 6, and 8). In order to trace possible significant trends occurring in students' contribution repertoire and knowledge advancement as grade level increases, both linear and non-linear correlation tests (Pearson) were performed on all data analysis measures, including "Ways of Contributing" main and subcategories, secondary contribution measures, as well as knowledge advancement measures. Table 8 displays results of correlation analysis measuring for both linear and curvilinear trends. For the linear component, students in each of the five classes were assigned a number corresponding to their respective grade level (1 for Grade 1; 2 for Grade 2; 3 for Grade 3; 4 for Grade 4; 5 for Grade 5/6), which was correlated with each variable listed below. For the quadratic component, each group was assigned a deviation score derived from the mean number of the groups (4 for Grades 1 and 5/6; 1 for Grades 2 and 4; and 0 for Grade 3). Correlation analyses were conducted using online statistics software *R*; the corresponding trend graphs were created using the trend line graphing function in Excel, with group-level results displayed (individual students are arrayed in the same, alphabetical order within each group).

Table 8

Linear and Curvilinear Relations between Grade Level and Ways of Contributing, Secondary Contribution and Knowledge Advancement Measures from in Each Group's Online Discourse Tested By Pearson Correlation Coefficients

	Linear Component	**Quadratic Component**
"Ways of Contributing" Main Categories		
Questioning	0.26**	0.21*
Theorizing	-0.23*	-0.00
Obtaining info	0.26**	-0.06
Working with info	0.07	-0.21*
Synthesizing & comparing	-0.03	-0.09
Supporting discussion	-0.06	-0.30**
"Ways of Contributing" subcategories		
Explanatory question	-0.04	0.10
Design question	0.167	0.01
Factual question	0.43**	0.16
Propose an explanation	0.10	0.10
Support an explanation	-0.08	-0.09
Improve an explanation	-0.16	-0.10
Seek an alternative explanation	-0.18	-0.01
Ask for evidence	0.24*	0.08
Report experimental results	-	-
Test hypotheses	-	-
Introduce new info (source)	0.32**	0.06
Introduce new info (experience)	-0.02	-0.26**
Identify design problem	-	-
Improve design problem	-	-
Support an explanation with evidence	0.07	0.19
Discard an explanation with evidence	0.00	-0.20*
Weighing explanations	0.18	0.16
Account for conflicting explanations	-	-
Make a comparison or analogy	-0.07	-0.04
Synthesize knowledge	0.02	-0.08
Initiate a rise-above	0.07	-0.06
Draw a diagram	0.17	0.04
Give an opinion	-0.12	-0.37**
Mediate discussion	0.24*	0.04
Secondary Contribution Measures		
Total # of notes	-0.00	0.42**
Total # of contributions	0.12	0.37**
Contributor diversity (main categories)	0.17	0.12

Contributor diversity (subcategories)	0.19	0.25*
Contribution richness	0.13	-0.16
Knowledge Advancement		
"Scientificness"	0.50**	0.02
"Epistemic complexity"	0.23*	0.01

Participants (n = 102) * p < .05. ** p < .01.

Findings reveal that there are a number of significant increasing linear trends across grade level, including the major category of "Asking Thought-Provoking Questions," "Theorizing," and "Obtaining Information," as well as the subcategories "asking a factual question," "asking for evidence," "introducing new information from a source," and "mediating

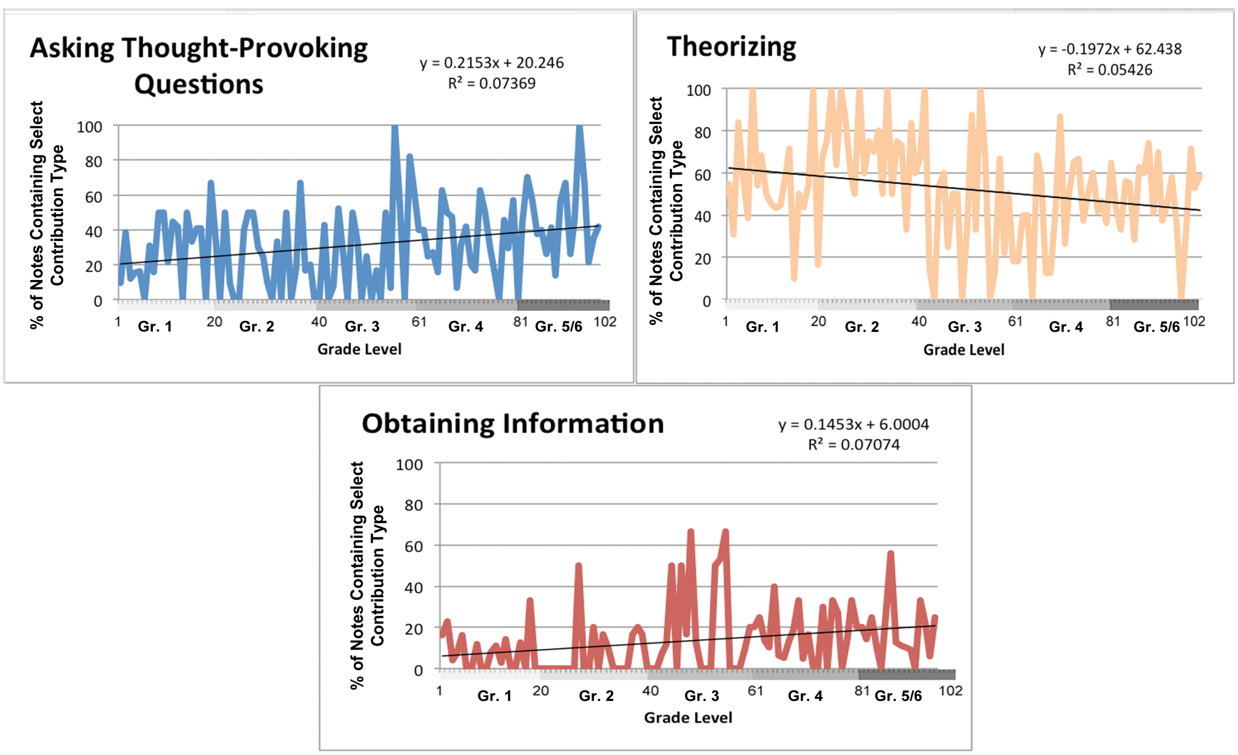

Figure 10. Significant linear trends across grades associated with main "Ways of Contributing" types in each group's online discourse.

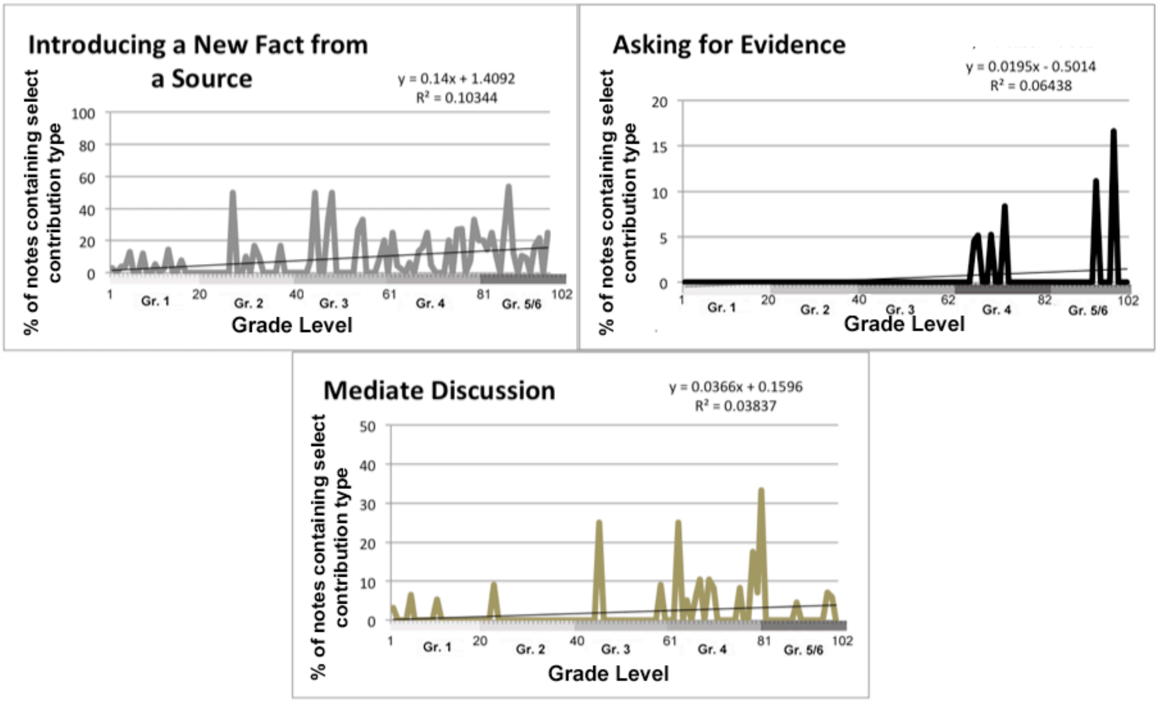

Figure 11. Significant linear trends across grades associated with "Ways of Contributing" subtypes in each group's online discourse.

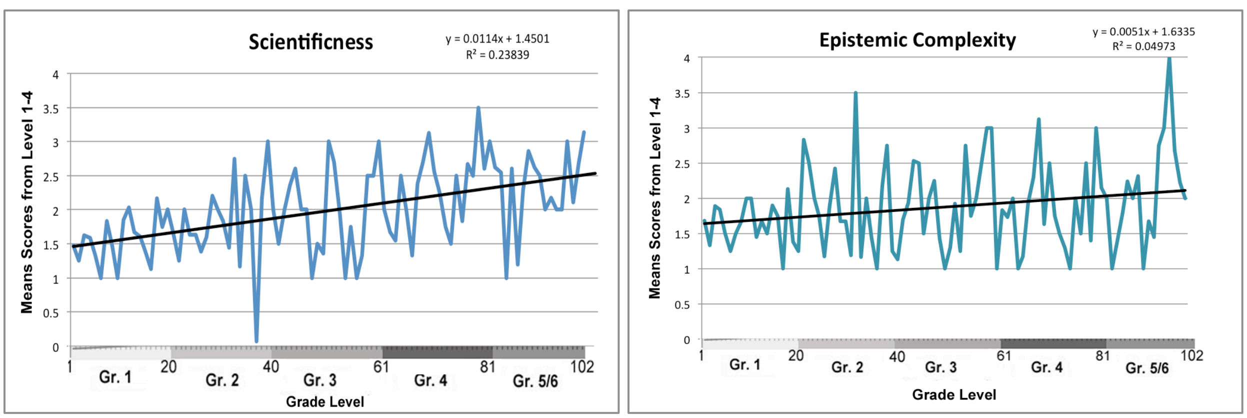

Figure 12. Significant linear trends across grades associated with knowledge advancement.

discussion" (see Figures 10 and 11). As Figure 12 shows, significant linear trends were also found across grade level in regard to "scientificness" and "epistemic complexity." These results all correspond to previous description of ANOVA comparison results on these same measures (see Section 4.3.3, 4.3.4, and 4.3.5), which showed that the Grade 5/6 students were asking more factual questions and offering more authoritative information to the discourse, the Grades 1 students tended to outperform others on "Theorizing," as well as findings that there was a marked increase in terms of knowledge advancement, including both "scientificness" and "epistemic complexity" of ideas as grade level increased.

Furthermore, analysis also reveals that curvilinear trends were found for the main categories "Asking Thought-Provoking Questions," "Working with Information," and "Supporting Discussion," as well as for the subcategories of "introducing new information from experience," "discarding an explanation with evidence or a reference," and "giving an opinion."

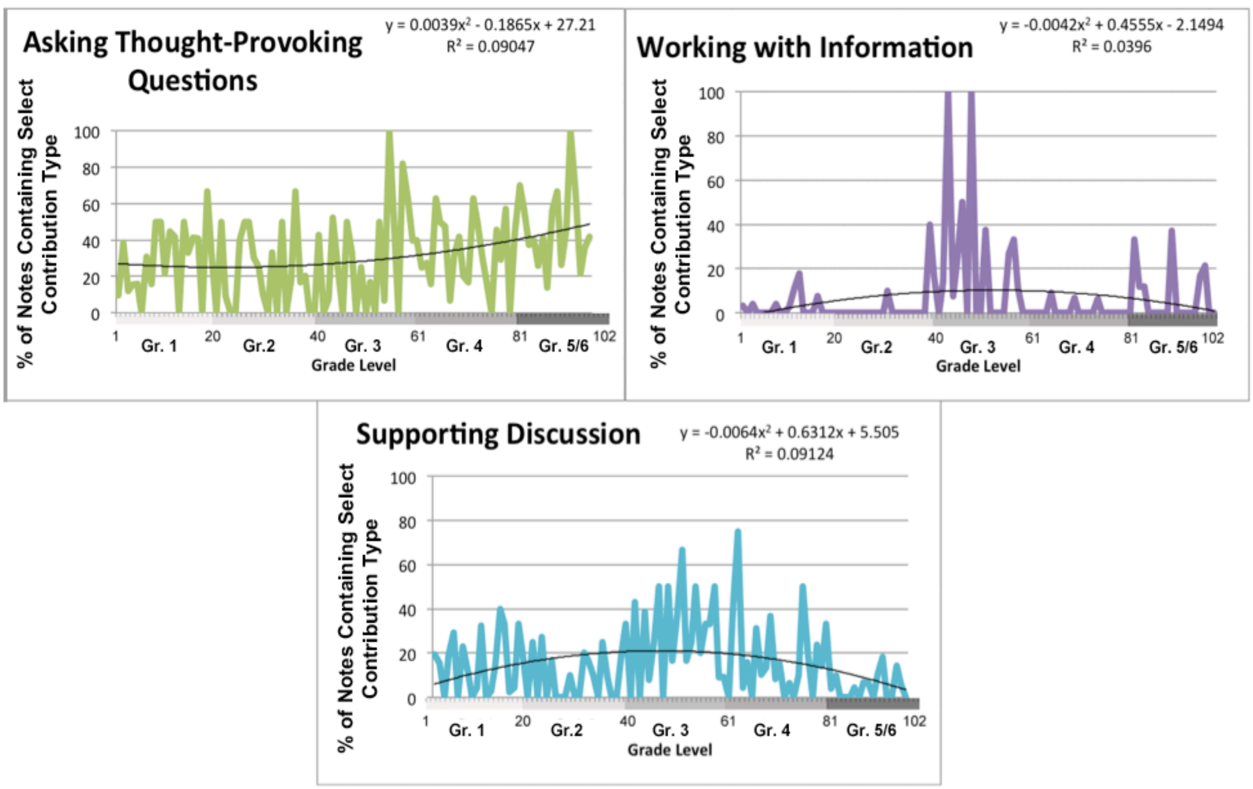

Figure 13. Significant curvilinear trends across grades associated with main "Ways of Contributing" types in each group's online discourse.

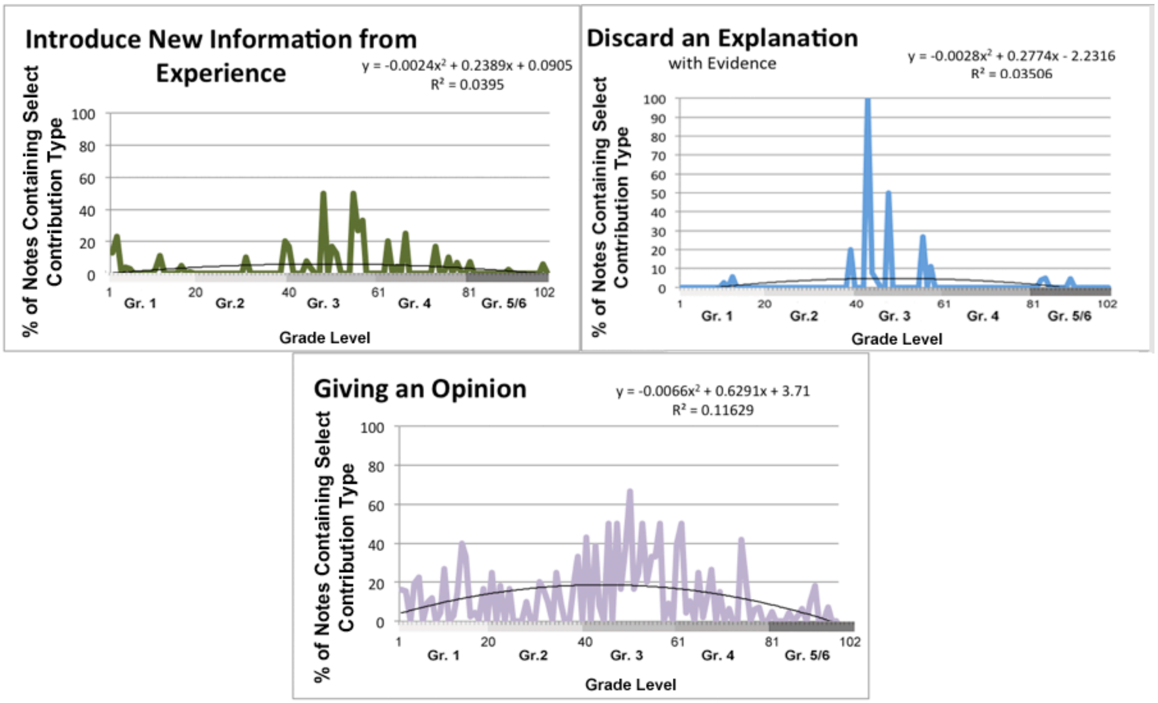

Figure 14. Significant curvilinear trends across grades associated with "Ways of Contributing" subtypes in each group's online discourse.

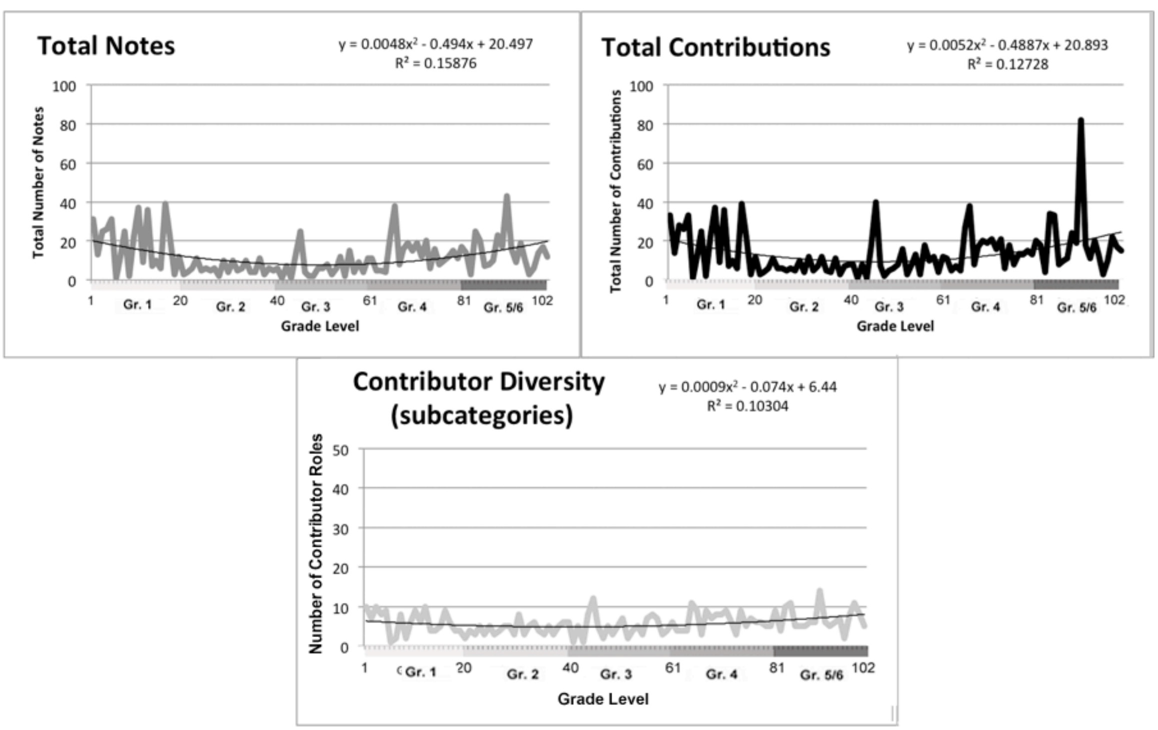

Figure 15. Significant curvilinear trends associated with secondary contribution measures in each group's online discourse.

Findings reported here underscore results described earlier that traced contribution frequencies across grade level (see Tables 2 and 3; Figures 4, 5, and 6), and also reinforce the results of ANOVA comparisons reported earlier in this chapter in section 4.3.3. For instance, it appears that Grade 1 class and the junior grade students both tended to engage in more “Asking Thought-Provoking Questions.” The Grade 3 class shows a higher engagement with “Working with Information” (see Figure 13) and a number of its corresponding subcategories (see Figure 14) than other grades—however, general engagement remains at a fairly low level overall. The trend for “Supporting Discussion,” including “Giving an Opinion,” also swells at the Grade 3 level, showing very little engagement in Grade 5/6. With respect to secondary contribution measures, significant non-linear trends were found in association with total notes, total contributions and contributor diversity corresponding to “Ways of Contributing” subcategories, with both the Grade 1 and the Grade 5/6 students tending to write more notes and make more contributions that the remaining groups on these measures (see Figure 15). That a curvilinear trend was found for contributor diversity on the subcategory level is provocative and supports the suggestion that students’ contribution repertoire is not necessarily limited by developmental factors alone, as mentioned previously (see Section 4.3.4.) Last, no significant curvilinear trends were found with relation to knowledge advancement measures.

4.4 Discussion of Results and Implications of Findings for Design Cycle 1

In sum, each of the Knowledge Building classes involved in this study demonstrated a diverse and dynamic discourse that supports the notion that elementary-aged students are quite capable of engaging productively in explanation-seeking dialogue and theory improvement. As Figure 3 shows, general patterns for ways of contributing to explanation-seeking discourse appear to be consistent across elementary school grades, with the greatest proportion of dialogue dedicated to "Theorizing," "Questioning," and "Supporting Discussion." This trend begins to change only in the upper junior years, with the most common contribution types being "Theorizing," "Questioning" and "Obtaining Information." Across all grades, "Working with Information" and "Synthesizing and Comparing" represented the two most rarely made discourse moves. Cross-grade comparisons show that as students get older, particularly as they enter the later junior years, students contribute more frequently to discourse moves like "asking factual questions," as well as contributions associated with "Obtaining Information" and "Working with Information." However, results of analysis also indicate that engagement with a variety of different discourse moves is not necessarily constrained by developmental factors, with the youngest participants in the study performing on par or outperforming their older peers on a number of contribution measures.

The impressive performance of the Grade 1 students in this study suggests that classroom culture can play a crucial role in supporting and enhancing student engagement in a variety of contributor roles integral to explanation-seeking discourse. So, what factors or conditions might help to explain the impressive performance of Grade 1 class? Can their performance be explained as the effect of a group that contains a large number of high-functioning students, or that exhibits an abundance of motivation and social cohesion, or perhaps to a uniquely gifted teacher, or to some mix of these possible attributes? Based on a number of years of experience at this particular school, I know that this particular Grade 1 teacher is not only an extremely gifted teacher, but a veteran at creating a Knowledge Building culture in her classroom. Databases from her past classes consistently demonstrate not only an impressive amount of writing and note production from students at such a young age, but high-level discourse that often exceeds curriculum targets for Grade 1. Furthermore, this teacher is known amongst her colleagues for her skill at fostering a safe and psychologically secure classroom atmosphere, as well as for her ability to engage every single member of the classroom into collective inquiry activities. Based on personal experience and the commentary of others regarding her practice, this teacher can be said to exemplify what Scardamalia (2002) refers to as a "Teacher C" model, which describes a teacher who successfully "turns strategic cognitive activity over to the students" (p. 71) and sustains a democratic and participatory Knowledge Building culture in her classroom.

A growing body of literature dedicated to exploring the basic social infrastructure that supports knowledge creation advocates the notion that a strong community culture has positive affects on Knowledge Building work (Bielaczyc, 2006; Truong, 2008). For instance, a study conducted by Zhang et al. (2009) that explored the classroom dynamics of a Grade 4 classroom over the course of three years revealed a number of benefits associated with the shift from a more centralized organization structure to one of "opportunistic collaboration" in which collective responsibility for knowledge advancement was gradually assumed by the students. Based on the outcomes of the study reported in this chapter, coupled with the known strengths of this particular Grade 1 teacher, one can surmise that this teacher and her students had created a thriving Knowledge Building culture in the classroom that was made manifest in part through the diverse ways her students contributed to their online discourse throughout their inquiry work.

Another influential factor that could help explain the impressive performance of these Grade 1 students is the amount of time they spent engaged in writing on the Knowledge Forum database. Students were able to deeply explore the problems they were wondering about because their inquiry was carried through over the course of a few months, with discourse on the database frequently and consistently woven into other research and investigatory activity. In efforts to identify possible distinctions between the elements of the Grade 1 Knowledge Building practice with the other 4 groups, I reviewed field notes and video transcripts from each group and traced the time dedicated in each of the five classes to Knowledge Building work, including "KB talks", which are whole group discussions dedicated to exploring questions, ideas, or activities relevant to Knowledge Building work, and to online writing time on Knowledge Forum. The Grade 1 class emerged as participating most frequently to both components. More specifically, in the span of two and half months, this class spent a total of 7.25 hours devoted to "KB talks", not including other research, field trips and experimentation, and participated in 25 sessions on Knowledge Forum that lasted between 30-45 minutes each. In comparison, the class that exhibited the least amount of time on the database spent a total of 3 hours engaging in "KB talks" and had approximately 12 sessions on Knowledge Forum that were roughly 20-30 minutes each. Recent research has shown that the consistent and quality interactions with Knowledge Forum to support collective Knowledge Building can significantly improve students' explanations and lead to deeper conceptual understanding (Hamal & Turcotte, 2012). In this case, prolonged time on the database proved to help young students to demonstrate a contribution repertoire as diverse as students three to five years older.

Further exploration of the performance of this class is beyond the scope of this research. However, the fact that these young students demonstrated capacities for engaging creative contribution types such as "seeking an alternative explanation" at levels that rivaled students up to five years older than them suggests that classroom culture can have a significant impact on students capacities to engage in collective dialogue, and gives rise to some questions that are central to the aims of this study: is it possible to create technological innovations that can affect similar outcomes with respect to expanding the ways students' contribute to explanation-seeking discourse? If so, to what extent can formative feedback designed to help students expand their contribution repertoire also help them to advance the knowledge of the group, which, in the case of this particular study, appears to follow a more stable developmental trend?

Based on the outcomes of this exploratory study, it was decided that work in Phase II would focus on a primary level grade. We wished to explore both the extent to which design experiments could enhance very young students' contribution repertoire as well as investigate ways to boost small children's abilities for engaging in authentic scientific inquiry and advancing scientific knowledge in the context of Knowledge Building practice. Our choice to focus on a primary level grade was not only influenced by the study findings, which reveal the potential of very young students to engage productively in explanation-seeking discourse, but was also supported by literature that both advocates for scientific inquiry to be started at early grades (Catsambis, 1995; Farenga & Joyce, 1999; Patrick, Mantzicopoulos, & Samarapungavan, 2009; Reid, 2003) and shows that even very young children are able to productively engage in scientific inquiry (Loss & So, 2009; Shutt, Phillips, Van Horne, Vye, & Bransford (2010). In fact, studies show that even five and six year old students are able to participate in important scientific processes, such as pose meaningful questions, make thoughtful observations, record evidence, give predictions about experimental outcomes, and revise ideas (Samarapungavan et al., 2008, 2011). Indeed, the young participants in this study also showed the capacity to contribute in meaningful and important ways to their scientific inquiry, even, in the case of the Grade 1 class, at levels that exceed expectation.

So, the goal for the research to be conducted in Phase II was to work with young children at a very early grade and explore ways to expand students' ways of contributing concurrently with helping them deepen scientific understanding. The following chapter reports work that builds off this initial study and tests both pedagogical and technological designs to enhance the explanation-seeking discourse of Grade 2 students doing Knowledge Building work in science.

4.5 Chapter Summary

This chapter reported the results of an exploratory study that investigates the ways that elementary school students from Grades 1-6 contribute to explanation-seeking dialogue in science. The chapter began with a description of the plan of analysis for the study. Following this, the contribution repertoire of each of the five groups was mapped. Overall, results from this exploration showed that contribution patterns remain fairly consistent throughout the primary years and into the first junior year (Gr. 4), with contribution repertoire only beginning to change in any significant way in the later junior years (Gr. 5/6). More specifically, the three most frequently made contribution types across Grades 1-4 included “Theorizing,” “Questioning,” and “Supporting Discussion,” in that order. In Grade 5/6 this pattern begins to shift, with “Theorizing” and “Questioning” remaining the two most commonly contributed discourse moves, followed up by “Obtaining Information.” With respect to the most infrequently made contribution types, both “Working with Information” and “Synthesizing and Comparing” appeared the least in discourse across all grades. These results suggest that, for primary grades, the categories of “Obtaining Information,” “Working with Information,” and “Synthesizing and Comparing” represent contribution types that could be targeted for pedagogical and technological interventions in subsequent design iterations.

Next, findings from correlation analyses that explore the relationships between different ways of contributing in a discourse were described. Findings from these analyses suggest that as students get older, a greater number of contribution types are more positively correlated to one another, with significant positive relationships in every grade.

Results also showed that grade level is not necessarily the determining factor with respect to the extent to which various contribution types are correlated; the youngest participants, those in the Grade 1 class, demonstrated the highest number of all five classes in correlations between different discourse moves. In addition, a positive correlation between secondary contribution measures, including total contributions and contributor diversity, was found to be consistently strong across all five grades. This finding is important as it suggests that, even at a very early grade level, Knowledge Building classes can demonstrate a dynamic and diverse discourse; it also suggests that expanding student contribution repertoire in the elementary grades might be enhanced by encouraging increased engagement in explanatory discourse, perhaps more so than having students assume different roles during scientific inquiry.

The final set of analyses included cross-grade ANOVA comparisons that were conducted in order to reveal any significant differences between grades with respect to ways of contributing and to help determine whether students' contribution repertoire expanded as grade level increased. Results from tests determining whether any significant differences existed between groups on knowledge advancement measures were also described. Findings showed a number of noteworthy outcomes. For instance, it appears that the older the students, the more factual questions were evident in the discourse. Furthermore, a rise in "asking factual questions" seemed to occur concurrently with "Obtaining Information," supporting the notion suggested above that older students tend to seek out information from authoritative sources in their Knowledge Building practice. However, it must also be noted that although the Grade 5/6 students worked significantly more with facts and authoritative information than the Grade 2 and 3 classes, no significant difference was found between these older students and the Grade 1 class on categories corresponding to "Obtaining Information." This finding supports notion that contribution patterns are not determined by developmental factors alone, but that influences such as classroom culture can have a strong impact on students' contribution repertoire. Findings from similar analyses on secondary contribution measures, including contributor diversity and total contributions made, mirrored the phenomenon that emerged when exploring differences across grades on ways of contributing categories—namely, the tendency for the Grade 1 class to outperform their primary peers.

Last, while contribution measures do not seem to follow a developmental trajectory across the elementary grades, analysis of depth of understanding scores showed a developmental pattern. For instance, the mean scores for "scientificness" and "epistemic complexity" for each class increased steadily from Grade 1 to Grade 5/6. Similarly, results of ANOVA comparisons reveal that the Grade 5/6 students posed more scientifically accurate theories than the Grade 1, 2 and 3 classes; the Grade 4 students also outperformed the Grade 1 students on this measure. Because of their impressive performance on ways of contributing measures, the Grade 1 students were expected to have greater corresponding knowledge advancement scores. Thus, these results challenge a main hypothesis of this research, namely that the more expansive the contribution repertoire, the greater the extent of knowledge advancement evident in the discourse. However, one possible explanation for these findings is that the younger students are more "knowledge poor" when it comes to scientific information (Bereiter, 2009), a finding reflected in the fact that their scores on the "scientificness" indicator of knowledge advancement are lower. Indeed, the findings reported above showed the theories and ideas posed by the older students reflected authoritative knowledge to a greater extent than the primary level students. Moreover, correlational analysis suggested that what helped the Grade 1 students improve their theories was the generation of reasons and justifications to support existing theories, while the more Grade 5/6 students worked with authoritative sources and factual information, the greater the likelihood for theory improvement in their discourse. Thus, the Grade 1 class contributed diversely and effectively to their discourse, but did not work to the same extent as the Grade 5/6 class with authoritative information. Interestingly, scores for "epistemic complexity" revealed no significant differences across grades, suggesting that all classes were engaged in the effort to create deeper explanations to the questions and problems of understanding that arose in their respective discourses.

Trend analysis supported findings reported from ANOVA comparisons, revealing linear trends for contribution types such as "Obtaining Information," "Theorizing," and "Supporting Discussion," but also nonlinear trends for discourse moves such as "Asking Thought-Provoking Questions," "Working with Information" and "Supporting Discussion." Curvilinear trends were also found for total notes, total contributions, and contributor diversity at the subcategory level, suggesting young students are quite capable of high levels of engagement and also of contributing diversely to their shared discourse.

This chapter closed with a general discussion about the study's findings, addressing the unexpected outcomes mentioned above in greater depth. This discussion also included commentary on the ways in which the results of this initial exploratory study inspired questions that directed next steps for the research.

CHAPTER 5: DESIGN CYCLE 1: EFFECT OF FORMATIVE FEEDBACK ON WAYS OF CONTRIBUTING TO EXPLANATION-SEEKING DIALOGUE IN GRADE 2

5.1 Chapter Overview

This chapter reports the first of two research design cycles that corresponds to Phase II of the study. For this stage of the project, I was interested primarily in assessing the dialogue generated by students to measure any growth in contribution repertoire and advancement of community knowledge that could be attributed to new pedagogical and technological tools geared to these objectives. This design cycle is comprised of a series of treatments integrated within a Grade 2 class doing Knowledge Building work in science throughout the 2011-2012 school year.[2] The chapter is organized as follows: i) introduction to the study, including a discussion on the contribution categories targeted; ii) explanation of the knowledge building principles informing the study design; iii) description of the participants and dataset analyzed; iv) outline of the study method and procedure; v) summary of results.

5.2 Co-designing the Knowledge Building inquiries

The study described in this chapter investigates the extent to which young students' ways of contributing to explanation-seeking dialogue can be enriched through educational innovations implemented within the context of authentic Knowledge Building practice. As the previous chapter reports, primary students are quite capable of engaging in dynamic scientific discourse

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[2] To note, a component of the research detailed in this chapter was presented at the 2012 Institute for Knowledge Innovation and Technology Summer Institute and was published in the conference proceeding. Here, I elaborate on each main component of the study and include additional qualitative analyses.

oriented towards explanation building, and also demonstrate the ability to generate a high number of thought-provoking questions as well as respond to these questions with a diversity of ideas and theories. Young students also displayed a capacity to build upon and refine their ideas, with all primary grade classes showing evidence of theory improvement in their knowledge building dialogue. Moreover, the achievements of the Grade 1 class highlighted in the last chapter suggest that young children can demonstrate productive engagement with important dialogue acts at levels equal or superior to those of older students. These findings indicate that elements of classroom culture and context can help boost students' ways of contributing to explanation-seeking dialogue in science. These results are provocative because they suggest that engagement with a variety of important discourse moves can potentially be bootstrapped by carefully designed supports that enhance the classroom environment.

For this research, both pedagogical and technological supports were tested to help students expand their contribution repertoire. More specifically, repeated metadiscourse sessions were implemented to engage students in collective reflection, and also tested contribution-oriented formative feedback generated by the metadiscourse tool in Knowledge Forum. Metadiscourse allows students to discuss the progress and setbacks in their inquiry on the whole, while automated visualizations help students gain perspective on the contribution makeup of their own dialogue. Embedding both metadiscourse and exposure to formative feedback within the regular Knowledge Building practices of the Grade 2 class allowed us to test the extent of each support for building students' capacity to engage diversely in explanation-seeking discourse. The main objectives for this design cycle was to explore the extent to which students could enhance and enrich their contribution repertoire by (a) engaging in repeated metadiscourse sessions regarding state and progress of group dialogue (b) engaging in repeated metadiscourse sessions coupled with the use of a formative assessment to visualize the contribution makeup of group dialogue as represented by the Metadiscourse Tool. The study reported in this chapter also investigates whether expanding contribution repertoire helped students to advance community knowledge as a whole. In order to do this, contribution types that were to be targeted in the intervention were identified. A principle-based design was then created to guide treatments, as described below.

5.2.1 Targeting contribution types

As identified in the previous chapter, contribution categories that primary school students appear to require further support for include “Obtaining Information,” “Working with Information,” and “Synthesizing and Comparing.” In consultation with the classroom teacher, it was decided that Grade 2 students would benefit from “Obtaining Information” and “Working with Information.” As results from the previous study show, “Obtaining Information” includes dialogue moves that appear more frequently at later grades in naturally occurring Knowledge Building work. Thus, this category represents a variety of discourse types that are both challenging yet are also more accessible to younger students than other difficult contribution types, such as those that fall under the category of “Synthesizing and Comparing,” for example. Discourse moves related to “Obtaining Information” should also support the second low-frequency category, “Working with Information.” For example, as described in Chapter 3, sophisticated use of information requires students to develop an understanding of information as something that not only describes a scientific phenomenon but helps provide evidence to corroborate, extend, or improve available ideas. Thus, a variety of facts and information from a range of sources, including authoritative texts, experimentation, and empirical observations, can enhance a dialogue and help students “use evidence to discard a theory” or “account for conflicting theories.” As the correlational analysis previously reported shows, the more new facts entered into the dialogue, the more likely students were to work with this information, including "discarding an idea with evidence" (as seen in the Grade 3 discourse) and improving a theory (as demonstrated in the Grade 2 dialogue). Boosting the presence of relevant information into young students' explanation-seeking discourse and encouraging them to work with this information is thus an important component for helping them carry their dialogue forward.

5.2.2 Creating a principles-based design

Three Knowledge Building principles served as foundational elements to the design of the research treatments implemented in this Grade 2 class. These principles, and their integration into the study design, are elaborated below:

(i) *Knowledge Building Discourse*: Boosting students' capacity to engage in explanation-seeking discourse is at the core of this research. Pedagogical techniques discussed with the teacher revolved largely around ways of enacting in the classroom the various components of explanation-seeking discourse as detailed in Chapter 2 (see Section 2.3). As Bereiter and Scardamalia's (2010) structural model indicates, an element of productive Knowledge Building discourse includes occasional periods of "metadiscourse." In this project, metadiscourse emerged as an area of collaborative discussion that the classroom teacher was interested in exploring in more depth in practice. She identified metadiscourse as an element of knowledge-building dialogue that emerged spontaneously at certain times within regular Knowledge Building talks, or within the context of active research. However, reserving space especially for the purpose of engaging students in prolonged periods of metadiscourse focused on advancing knowledge represented a new element she was keen on integrating more purposefully into the Knowledge Building practice of her classroom. It was decided that a series of special "KB Talks" devoted to metadiscourse would be integrated within the students' inquiry time as a pedagogical treatment geared towards enhancing students' Knowledge Building dialogue. Questions that students would be addressing would include:

- Are we answering our questions?
- Are we going deeper with our theories?
- Are we bringing in useful information that is helping us to develop our ideas?
- Are we stuck on a problem? What can we do to get "unstuck"?
- Why is it important to stop and reflect on our inquiries?

While the literature exploring the role of metadiscourse in students' Knowledge Building practice remains limited, existing studies position metadiscourse as a critical component of Knowledge Building work. For instance, van Aalst (2009) identifies metadiscourse as a key condition of an innovation ecology that can enable knowledge creation. Studies also show that metadiscourse can help students in a range of important ways, such as recognizing shared knowledge advances, identifying setbacks, identifying next steps, setting goals and drawing links between them, connecting ideas, articulating new and promising questions, and establishing deeper ties between authoritative knowledge and newly identified problems (Zhang et al., 2009; Zhang & Messina 2010; Zhang, Hong, Scardamalia, Teo, & Morley, 2011).

ii) *Constructive use of authoritative sources:* This principle is central to a range of discourse moves in explanation-seeking dialogue and corresponds directly to "Obtaining Information" and "Working with Information." In explanation-seeking discourse, information is introduced into the discussion from a range of sources including books, educational websites, experiments, empirical observations and so on. As described in Section 2.3.4 of this thesis, productive work with information amounts to more than the amassing information; it requires students to put new information to work to improve their ideas, and is necessary for students to verify tests, corroborate evidence, fill knowledge gaps, and pursue promising avenues to help them advance their knowledge. In order to boost the presence of contributions that correspond to “Obtaining Information” and “Working with Information” in students’ discourse, the teacher and I created two versions of a scaffold that the teacher and I would introduce into the Knowledge Forum environment. The scaffold included the following supports: “This information helps to explain” and “This information is important because.” As noted, studies have indicated that information introduced into a database can often be viewed as unproblematic and that the inclusion of interesting facts does not necessarily inspire questioning or further theorizing (van Aalst, 2009). Also, inability to use sources constructively such as uncritically copying and pasting text, or accepting information from web resources or textbooks as indisputable, can hinder idea improvement (Law & Wong, 2003). So, these scaffolds were designed to encourage students to choose “useful” facts that were not just “interesting” but advanced the discourse, and helped them explain the relevance or function of these facts to the wider inquiry. Both scaffolds were introduced to students in metadiscourse sessions in which they discussed which scaffold they would find useful. The new scaffold would be available to Grade 2 students and would be accessible to the students whenever they worked on Knowledge Forum.

iii) Concurrent, transformative and embedded assessment and *emergent knowledge*: The principle of concurrent, transformative and embedded assessment refers to effort taken on behalf of the community itself to identify advancements or setbacks in its own knowledge building endeavours on a continual basis. As described, one objective of the study was to design and refinement of new technological designs that could provide formative feedback to students as they engaged in their regular knowledge building work. To this end, two forms of feedback were tested designed to help students take a “bird’s eye view” of their own discourse:

(a) *The Metadiscourse Tool:* To explore ways to expand students’ contribution repertoire using automated feedback, “metadiscourse” visualizations were tested, to help students monitor in real time their discursive moves corresponding to scaffolds in Knowledge Forum (see Figure 16).

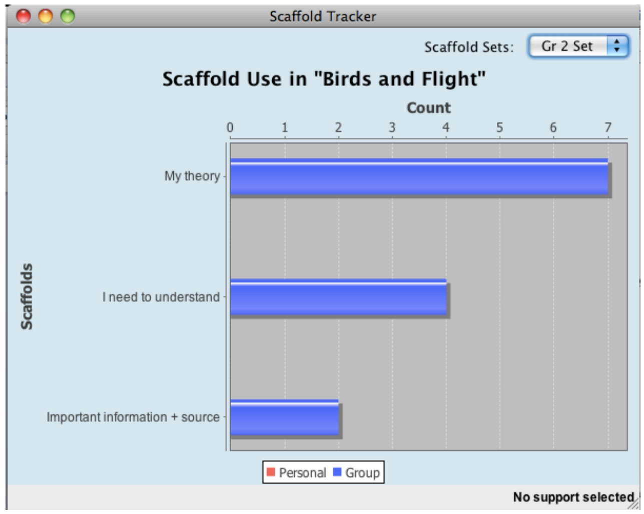


Figure 16. Metadiscourse Tool visualization showing bar graph of scaffold use.

The Metadiscourse Tool works interactively with Knowledge Forum notes (see Figure 17). For example, a student can click on the Metadiscourse Tool icon to view the bar graph for the current view. If, while looking at the visualization, the student wanted to review all the theories contributed so far to that view, a simple click on the “My Theory” scaffold would result in a display of notes corresponding to that scaffold.

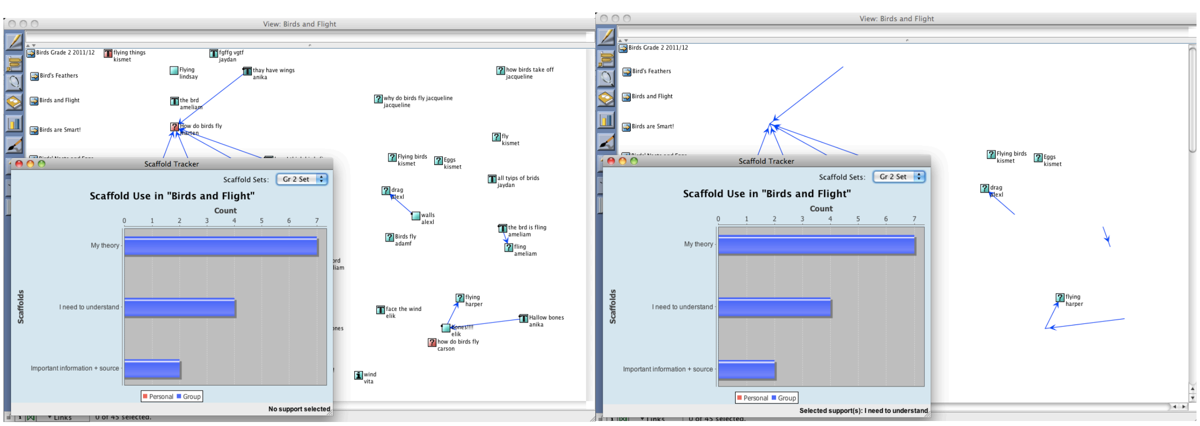


Figure 17. Metadiscourse Tool showing interactivity with Knowledge Forum notes. The tool window opens at the bottom right of a view (left). When a single bar is clicked on the graph, only those notes that feature that particular scaffold appear on the corresponding view (right).

The classroom teacher was eager to use the Metadiscourse Tool as a way to extend discourse around the scaffolds—something that she had already attempted to a limited extent. As she describes, she typically devotes a portion of the first or second "KB talk" of the year to discussing the verbal scaffolds used in Knowledge Forum, what they mean, why they are there, and why they are important. She does this so that the students not only reacquaint themselves with important Knowledge Building vocabulary, but also so that the class acknowledges together why using the scaffolds in Knowledge Forum is necessary as part of their routine work on the database. Talking about why contribution types are significant is important to help students make meaningful connections between their offline and online discourse and to cultivate productive habits when working with the technology.

At this particular school, teachers collectively decided to set standard scaffolds for various grades (see Figure 18). The Grades 1 and 2 classes use a uniform set of scaffolds that include the following three verbal supports: "My theory," "I need to understand," and "Important information + source." These supports map directly onto three corresponding "Ways of Contributing" categories, namely, "Asking Thought-Provoking Questioning," "Theorizing," and "Obtaining Information." Other scaffolds such as "The evidence shows that," "we need an experiment to" or "this theory could be improved by" correspond to the remaining discourse categories, "Working with Information" and "Synthesizing and Comparing." Discourse moves that fall under these discursive categories, such as "weighing conflicting ideas,"

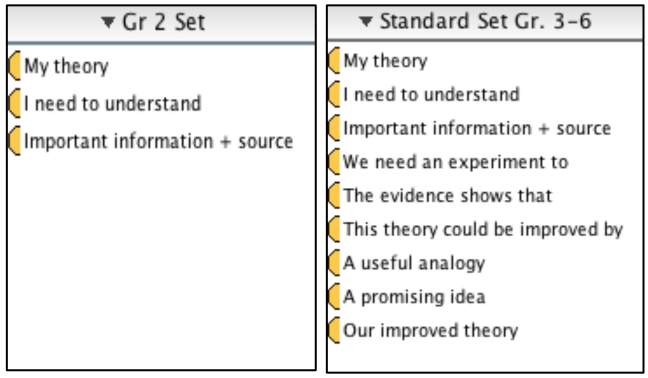


Figure 18. Knowledge Forum scaffold sets for primary students (left) and junior students (right).

"synthesizing available ideas," or "rising-above" to higher-level conceptualizations, are by nature very challenging. For example, "initiating a rise-above entry" calls for reflection on various aspects of community knowledge, time and cognitive effort, and coordination with others, thus challenging for any knowledge builder, regardless of age. While increasing the contribution levels of Grade 2 students in "initiating a rise-above entry" or "synthesizing available ideas" was not a targeted outcome, the teacher and I believed that addressing these important contribution types through group metadiscourse talks would be important for raising the level of online discourse.

(b) *Word Clouds:* To help facilitate metadiscourse discussions, a series of different word clouds were created visualizing key terms and concepts relevant to various streams of inquiry that emerged in students' own discourse. Word clouds refer to representations of textual data that are based on schemes of significance or popularity expressed through visual properties like font size, color, position, or weight (Bateman, Gutwin, & Nacenta, 2008). Word clouds have been shown to be educationally beneficial in a number of ways. For example, Word Clouds can summarize content in helpful ways (Schrammel, Leitner, & Tscheligi, 2009), provide useful overviews of knowledge that highlight key concepts (Hearst & Rosner, 2008), signal individual or social interactions in a dialogue, as well as act as "suggestive device[s]" for underlying phenomena in source data (Xexéo, Morgado & Fiuza, 2009) and illuminate implicit or hidden relationships in unstructured data (Koutrika, Zadeh, and Garcia- Molina, 2009). Word clouds can also aid in semantic exploration and comprehension of data by users (Bateman, Gutwin, & Nacenta, 2008).

In this design cycle, two different types of Word Clouds were used, including "Contribution Clouds" and "Concept Clouds" (see Figure 19). These visualizations were shown to students during metadiscourse sessions to provide an overview of the dialogue that students had generated and to help them review the important terms they were using over the course of each study unit, which spanned 16 weeks. There were three different variations of

Figure 19. Word Cloud visualizations that supported the metadiscourse sessions, including Concept Clouds (top), and Our Contribution Clouds (bottom).

"Contribution Clouds" that included "Our Theories," "Our Questions," and "Our Information" clouds. Beyond facilitating recall, "Contribution Clouds" were geared to help students reflect on the state of their shared knowledge and to make useful observations about the contributions comprising their discourse. For instance, an "Our Questions" cloud that contains a single question that is much larger than all others serves to highlight a query that many students in the group may be wondering about. Thus, this contribution may represent a question that has generated a number of theories that can then be reviewed in order to be synthesized and advanced. However, if this question has not inspired theorizing, then students can discuss why, and perhaps begin pursuing a new avenue of inquiry. This type of visualization can also help students see that this one particular question has been written multiple times, as it is visually larger than all the rest, and thus need not be contributed again in the online discourse, but, if deemed worthy of further pursuit, should be investigated through continued theorizing and research.

With respect to "Concept Clouds," three different types were used: Clouds that depicted the most frequent terms that the students were using in their naturally occurring dialogue over time ("Our Words"); clouds that depicted key words that experts frequently used when talking about those same phenomena ("Expert Words"); and clouds that allowed students to assess the extent to which the words characterizing their discourse mapped onto those used in the expert dialogue, by means of colour-coding ("Our Shared Words"). For instance, as Figure 9 shows, the expert terms featured on the "Expert Words" cloud also comprised the terminology displayed on the "Our Shared Words" cloud. However, in this cloud, expert terms that students also used in their own online discourse are coloured red, while terms that students have not yet used remain black.

These visualizations were geared to help students gain a sense of the semantic field of their discourse, and to enable the community to trace the use and longevity of new terms in their discourse over time. For instance, variations in word sizes helped make clear terms that were dominating the discourse at any point in time, underused or unrecognized key terms, terms useful to the problem at hand, and so on. Gaps in vocabulary between students and authoritative sources, as illustrated in the “Our Shared Words” cloud, provide helpful support for expanding the field of discourse. Discussion of these visuals as part of metadiscourse sessions helped position the concepts represented as objects of public discourse—artifacts that the community could rally around during periods of reflection. The teacher also planned to print out each version of the “Our Words” visualizations after they were discussed collaboratively so that children would see changes over time. The “Expert Words” cloud was also added to the background of the Knowledge Forum view on which students worked so that they would have continual access to these terms and could review them at their discretion during their time on the database (see Figure 20).

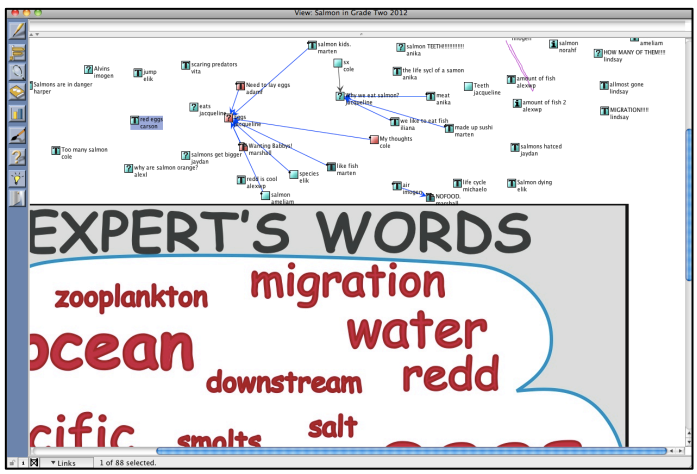


Figure 20. Shared Knowledge Forum view for the Grade 2 Salmon study, with “Expert Words” visualization embedded in the background.

All word clouds represented formative feedback, and as such were created at various intervals throughout the inquiry, with changes in visualizations based directly on terms emerging from students’ own writing on Knowledge Forum. The “Expert Word” clouds were the only images that did not show student’ own words, but these images were still created emergently, responding to specific inquiry threads that arose in student dialogue, such as “how do birds fly?” or “how do salmon reproduce?” The source data for the different “Expert Word” visualizations was derived from a variety of documents that represented three levels of difficulty. For the bird study, the sources used included the following: text from a webpage geared towards children entitled "Flight and Locomotion" from the "The Wild Classroom" website (http://www.thewildclassroom.com/biodiversity/birds/aviantopics/avianflightandlocomotion.html); content from a Wikipedia article entitled "Bird Flight" (http://en.wikipedia.org/wiki/Bird_flight) as a source aimed at a general (adult) audience; finally, an article from a scientific journal entitled "Biomechanics of bird flight" (Tobalske, 2007), which represented the highest-level source text. Similarly, source text for the "Expert Word" clouds used in the salmon unit included: text from the "Salmon Life Cycle" webpage, part of the resource package for the "Dialogue for Kids" website which is affiliated with the Idaho Board of Education and is geared towards elementary schoolchildren (http://idahoptv.org/dialogue4kids/season11/salmon/facts.cfm); the "Life Cycle" section of the Wikipedia article on salmon (http://en.wikipedia.org/wiki/Salmon), again, aimed at a general audience; and a "Salmon spawning behaviour" resource page, taken from a postsecondary level environmental science program (http://archives.evergreen.edu/webpages/curricular/2001-2002/envstu01/ChumSalmon.html).

To generate the "Expert Words" word clouds from these sources, the entire textual content of these documents was uploaded to Wordle (www.wordle.net), which is a free, automated word cloud generator. The threshold in each case was set at approximately 20-25 words so that the output displayed in each cloud would not be too cluttered and would remain comprehensible to young students. The Wordle generated clouds were then manually reproduced in Adobe Illustrator so that the "Our Shared Words" word cloud could be colour-coded to show the overlap between students' words and expert terms. The "Our Contribution" clouds were also created manually in Illustrator, with students' original wording preserved as much as possible and adapted only slightly in the case of common questions or theories (for instance, the question "how are birds able to fly?" which was posed a total of five times in the database with slight variation in wording was phrased in the simplest manner on the word cloud—"How do birds fly?"—and sized appropriately to communicate its frequency). While this process was time consuming, it was necessary in the absence of any automated tool that could perform similar functions.

5.3 Method and Analyses

The following section outlines the method and approach to analyses used in this design cycle, including a description of the participants, an outline of the treatment procedure and data sources, as well as an overview of the plan of analysis.

5.3.1 Participants and classroom context

Participants for this study included a cohort of 21 students (11 boys, 10 girls). Of these students, 20 were studied over two consecutive years, from Grade 1 (2011) to Grade 2 (2012). As mentioned in Chapter 3, the school has only one class per grade, so students typically move as a cohesive and unified group from Grade 1 to Grade 2. In the case of this cohort of students, one was present in Grade 2 but not in Grade 1. Therefore, in any cross-grade comparisons, this student was excluded from analysis. The study also included another 21 students (10 boys, 11 girls) from a previous Grade 2 class (2011).

There are two experimental groups and one benchmark group in this study. The first experimental group—Group A— consists of 11 students (six boys and five girls). The second experimental group—Group B—consists of 10 students (five boys and five girls). Students in both of these groups did not receive any special design experiments in Grade 1, 2011, but engaged in design experiments in Grade 2, 2012. The 21 students from the Grade 2, 2011 class also were not engaged in any design research. Thus, the work generated by the Grade 1, 2011 class and the Grade 2, 2011 class provides benchmark data for the study.

The same teacher, in consecutive years taught both of the Grade 2 classes, and was also involved in the co-design team. As such, she participated in the design and implementation of all the educational treatments conducted in this study. It is worth noting that both the Grade 1 and Grade 2 teachers in this study also taught the same grades for the study reported in Chapter 4. All participating students were introduced to Knowledge Building pedagogy in Kindergarten, and Knowledge Forum technology in Grade 1. Thus, all students had the same amount of experience in both the pedagogy and technology.

In Grade 1 (2011), students participated in a Knowledge Building study on “Water”, which included considerations of the water cycle, evaporation, and irrigation. The study lasted approximately three months. In addition to whole-class “KB” talks, Grade 1 students also participated in active research and conducted a number of classroom experiments so that students' discourse was inspired and informed by hands-on and empirical observation as well as use of written materials. Students also went onto Knowledge Forum as an extension of discussion to enter notes, build onto each other's ideas, and incorporate the questions, observations and information they gleaned from experiments conducted in class onto the online database.

In Grade 2, students engaged in two Knowledge Building units under the “Understanding Life Cycles” curriculum stream, with a focus on “Growth and Change in Animals.” The Grade 2 class began with a study on “birds” and followed this up with a unit on “salmon.” As outlined in the Ontario Curriculum Standards for Grade 2 (2007, p. 59), the overall expectations for learning in this stream include the ability to:

- Assess ways in which animals have an impact on society and the environment, and ways in which humans have an impact upon animals and the places where they live.

- Investigate similarities and differences in the characteristics of various animals.
- Demonstrate an understanding that animals grow and change and have distinct characteristics.

More specific expectations call for students to demonstrate the capacity to do the following:

- Investigate the ways in which a variety of animals adapt to their environment and/or to changes in their environment.
- Us[e] scientific inquiry/research skills and knowledge acquired from previous investigations to investigate the basic needs, characteristics, behaviour, and adaptations of an animal of their choice.
- Use appropriate science and technology vocabulary, including life cycle, migration, adaptation, body coverings, and classify, in oral and written communication.

Because the number of computers in the Grade 2 class was limited to eight, the students were split up in a rotation for their Knowledge Building (KB) sessions in which half of the students left the classroom for library time and the other half engaged in Knowledge Building work. The rotation groups were chosen randomly, within the constraints of having an equal number of boys and girls present in each group, and persisted throughout the school year. Although their Knowledge Building sessions occurred on different days, all students in a single class worked in the same Knowledge Forum view, and contributed to the same group dialogue. For both units, the Grade 2 students typically had one 45-minute session a week dedicated to knowledge building, referred to as “KB time.” During this period, students engaged in active research or whole group “KB talks” in which they discussed questions, ideas, and so on, integral to their given study. After discussion, students were given 20 minutes to enter their ideas, questions, theories, etc., into the Knowledge Forum database. For both units of study, students engaged in active research and used a variety of sources, including books, websites, and videos, to increase their knowledge on birds and salmon. Students in both classes also examined objects such as owl pellets, feathers, and nests, dissected fish, as well as raised salmon in a classroom tank as part of the “Classroom Hatchery” component of the Lake Ontario Salmon Restoration Program (see http://www.bringbackthesalmon.ca/) (see Figure 21). Similarly, in both years, this tank was also placed under the classroom “Wonder Wall”, which displayed all of the initial questions that the children had about salmon and the salmon eggs at the beginning of the investigation. Students would pursue these questions and develop their ideas throughout the sustained inquiry. Thus, students in both years had rich environments to support their Knowledge Building work.

Figure 21. The Grade 2 classroom salmon tank with incubating salmon eggs.

5.3.2 Procedure

While both the 2011 and 2012 Grade 2 classes engaged in collaborative discourse both online and offline, the experimental 2012 class engaged in a series of special "KB talks." Within the 2012 class, the two student groups (Group A and Group B) each received a different variation of the metadiscourse intervention. Group A and B participated in a total of seven metadiscourse sessions over the course of eight months. During these discussions, the teacher encouraged students to reflect on the state of their Knowledge Building discourse, with the goal of deepening discussion and advancing group knowledge. Select metadiscourse sessions for both Group A and Group B were facilitated by the use of the Word Clouds visualizations. Additionally, students in Group B were exposed to the Metadiscourse Tool. Thus they were engaged throughout in charting their contributions to their online discussion and using graphs generated by the tool to reflect on knowledge advances. Because both groups were working on the same database, both the Word Cloud and the metadiscourse visualizations that were shown to students reflected work done by the whole class. A detailed breakdown of interventions that occurred over the course of eight months is outlined below:

5.3.3. Metadiscourse sessions

In the Grade 2, 2012 class, the bird and salmon units ran consecutively from September 29th to February 2nd, and then from February 16th to May 16th. Embedded throughout this inquiry were a total of seven metadiscourse discussions. Several weeks separated each session in order to give students ample time to participate in Knowledge Building work, including research, outdoor trips and other activities. At various times throughout the year, the intervals between sessions were not equally distributed due to a variety of scheduling circumstances (e.g. the class play, holidays, etc.) that affected the timing of Knowledge Building periods in the class. The schedule of metadiscourse sessions ran as follows:

- <u>October 20th</u> —This was an introductory metadiscourse session. Students reviewed the major lines of inquiry they had generated so far regarding the life cycles of birds and discussed the significance of scaffolds to knowledge building work. Both Group A and Group B were introduced to the concept of metadiscourse, and viewed the Word Clouds. Group B also viewed the metadiscourse tool for the first time.

- November 3rd —This metadiscourse session was directed towards the study's targeted contribution types, including "Obtaining Information" and "Working with Information". Students discussed the pre-existing scaffold "important information + source," and were introduced to the new scaffolds "this information is important because" and "this information helps explain." Students were asked to select a scaffold for further use (unanimously choosing the former). A wider discussion about the inquiry unit then followed in which students discussed the ways of contributing that dominated their discourse, and how these contributions types either helped or hindered efforts at improving ideas. Group A reflected on scaffolds as well as their inquiry work solely through discussion, whereas Group B used the metadiscourse graph to help them track contribution types evident in their discourse so far.
- December 15th - This session focused specifically on inquiry around owl digestion, since questions surrounding the owl pellets that were dissected in class was dominating group discussion at this particular time. Group A and B examined Word Clouds, while Group B also used the Metadiscourse Tool to help them reflect on the contribution types they were making in relation to this specific inquiry stream.
- January 12th —This session was focused on flight, as questions regarding how birds fly dominated the conversation, both online and offline, at this point in the inquiry. Students assessed their progress through reflective discussion and by examining Word Clouds (Group A and B), as well as by examining the contribution makeup of their dialogue by examining the metadiscourse visualization (Group B).

- February 2nd —By this time, students were transitioning to their study on salmon. As such, this discussion represented their final metadiscourse session on birds. Both groups reviewed their major questions, assessed how far they believed they had gotten in their pursuit of explanations, and also discussed ideas to questions they felt they had not addressed satisfactorily in their online discourse. Both groups worked with the Word Clouds in this treatment.
- March 8th —This session focused on going over students' initial ideas and questions about salmon. The start of this unit coincided with the beginning of the "Classroom Hatchery" program, which gives students the opportunity to raise salmon in their classrooms and then release them back into the wild with the help of representatives of the program. At this point, students were full of questions about the salmon eggs that had been brought into the classroom by a biologist from the program. Thus, this metadiscourse session was dedicated largely to discussing ways for students to pursue their existing questions. As in earlier sessions, both groups' conversations were facilitated by Word Clouds, while Group B also reviewed the Metadiscourse Tool visuals to track and discuss emerging contribution patterns.
- March 15th —This session focused on why and how salmon reproduce. This line of inquiry aroused a great deal of student interest since they had been observing the salmon eggs in the tank everyday. Students were invited to reflect on ways they could improve their existing ideas in the final weeks of the inquiry. Again, both groups examined the World Clouds, while the Metadiscourse Tool was viewed by Group B alone.
- April 18th —In this final reflective discussion, students were eager to answer questions that remained unaddressed in the database, made explicit by means of the Word Cloud visualizations. Students were encouraged to think about ideas that connected the major themes that emerged across both units. Also, Group B was asked to reflect on the

Metadiscourse tool feedback, and discuss contribution types that remained marginal, as evidenced in the feedback, and why they remained difficult for students to engage.

5.3.4 Dataset

The dataset for this investigation involved work from Grade 1 and Grade 2 students from primary science units through which they were engaged in scientific questioning and theorizing. There were different curriculum streams: Grade 1 (Understanding Earth and Space Systems) and Grade 2 (Understanding Life Systems). The data analyzed consisted of the following: i) Grade 1, 2011—195 notes on the unit "Water" generated across three Knowledge Forum views; ii) Grade 2, 2011—248 notes across four views, from both the bird study (114 notes, three views) and salmon units (134 notes, one view); iii) Grade 2, 2012—203 notes across eight views from their bird study (175 notes, seven views) and salmon units (90 notes, one view); iv) Video of student "KB talks" and Metadiscourse sessions from the Grade 2, 2012 class that supplement student notes by providing qualitative information about students' ideas and interactions.

5.3.5 Plan of analysis

Data analysis is identical to that utilized in the study reported in Chapter 4, Section 4.2.3. The method of analysis for each measure is reiterated briefly below, and includes hypotheses about experimental outcomes:

(a) Contribution Measures: i) *Contribution repertoire*: Notes were coded according to the previously described "Ways of Contributing" scheme (see Chapter 3, Section 3.6) in order to track potential expansion of contribution repertoire; ii) *Secondary contribution measures*: Notes were also subject to analysis to determine the following: i) total number of notes written; ii) total number of contributions made; iii) contribution diversity on both the "Ways of Contributing" main and subcategories; iv) contribution richness. The hypothesis was that these measures would be higher than the benchmark Grade 2, 2011 for both Groups A and B, as a consequence of ongoing exposure to feedback visualizations reflecting the contribution makeup of students' dialogue; more specifically, Group B—additionally using the Metadiscourse Tool, would show significant advances over Group A.

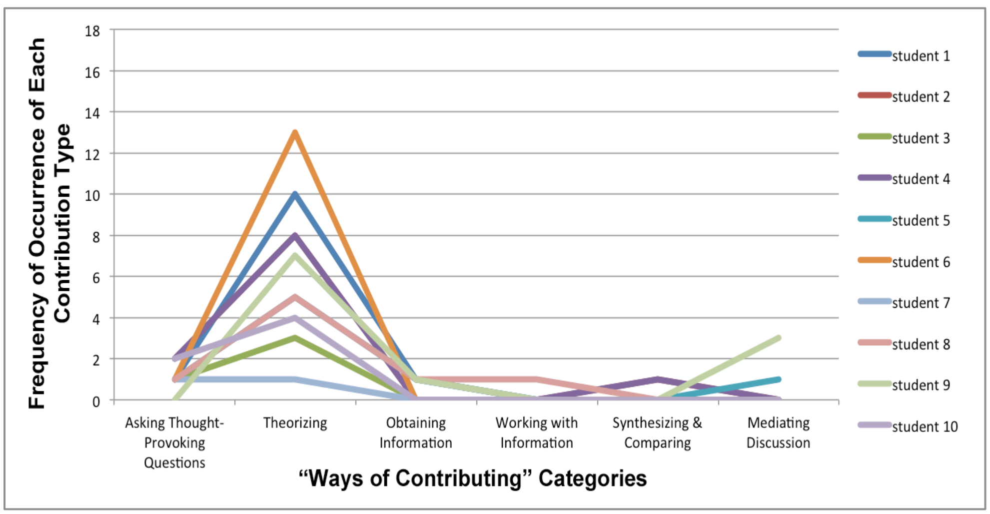
(b) Knowledge Advancement: Notes from the online discourse that were coded under the "theorizing" category were selected and subject to further analysis to assess community knowledge advancement, which was evaluated using the scales for "“scientificness”" and "“epistemic complexity”" (Zhang et al., 2007) previously described. Another prediction was that the Grade 2, 2012 class would exhibit greater knowledge advancement as a result of continual periods of reflection about the state and direction of their dialogue. Furthermore, it was hypothesized that Group B from this class would demonstrate a greater degree of knowledge advancement than Group A as an effect of metadiscourse enhanced by feedback that gives a meta-perspective on group discourse.

5.4 Results

The section below details the results of analyses, including description of findings for both contribution and knowledge advancement measures.

5.4.1 Did students' contribution repertoire diversify from Grade 1 to Grade 2?

One major objective of this research was to boost students' contribution repertoire through technological and pedagogical interventions. To rule out the possibility of any pre-existing differences between groups with respect to their ways of contributing before the treatments, a series of independent sample *t*-tests were run comparing Group A and Group B's performance on each contribution measure in Grade 1. These included comparison of students' contribution repertoire, as well as the secondary contribution measures of total notes, total contributions, contributor diversity (corresponding to both main and subcategories), and contribution richness. Results showed that there were no significant differences with respect to any measure (see Figures 22 and 23). Furthermore, the contribution patterns revealed in the class reflected similar patterns for this grade level, as seen in the initial study presented in Chapter 3, with the most common contribution types falling into the categories of "Theorizing" and "Questioning" (see also Chuy, Resendes, Chen, et al., 2011).



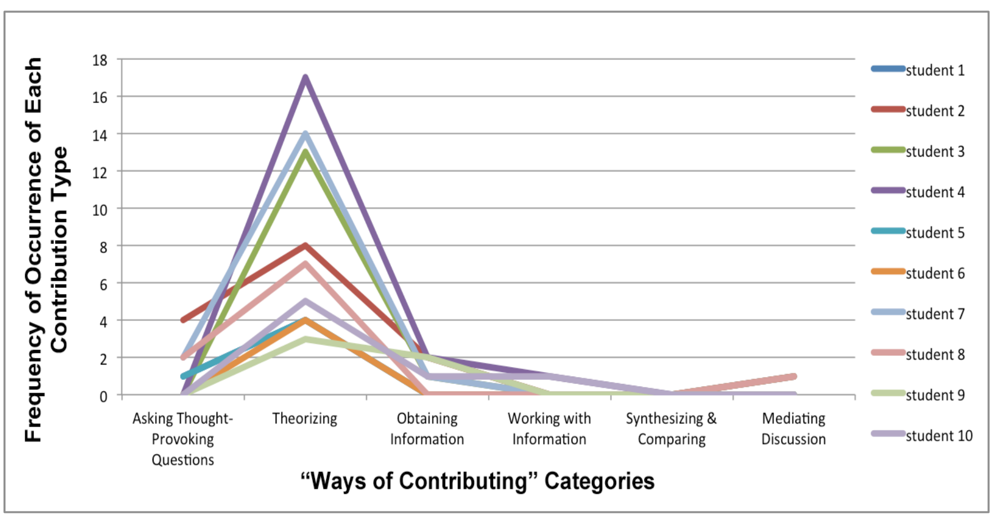


Figure 22. Contribution profiles (*n*) of the online discourse of Group A (top) and Group B (bottom) in Grade 1, 2011.

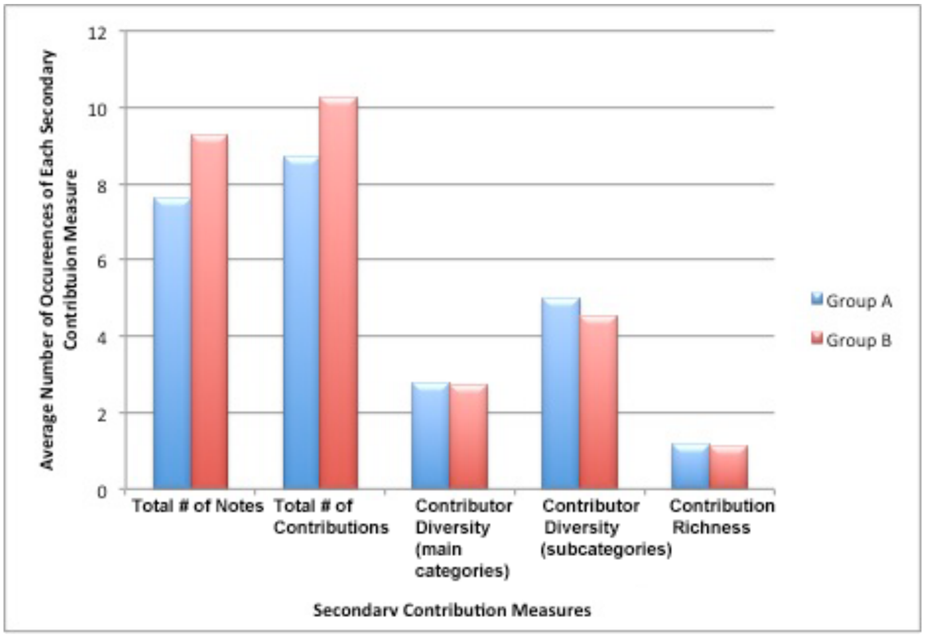


Figure 23. Means (*n*) for secondary contribution measures for Group A and B in Grade 1, 2011.

The same tests were then run on both groups in Grade 2. Results indicated no significant differences in regards to ways of contributing (see Figure 24), but did trace a notable difference on three of five secondary contribution measures (see Figure 25), with Group B outperforming Group A on the following: Total contributions ($t(19) = -2.802$, $p < .05$), total number of notes ($t(19)$ -.2.33, $p < . 05$), and contributor diversity for "Ways of Contributing" subcategories ($t(19)$ -2.12, $p < .05$). Thus, results indicate that the Metadiscourse Tool helped students make more types of contributions more often; it did not lead to significant difference in one type of contribution over another. Findings also indicate that use of the Metadiscourse Tool coupled with reflective discussion on the contribution makeup, direction and progress of student discourse helps students contribute more diversely—namely with respect to the finer-grained subcategories—and also contribute much more often. There was no significant difference with respect to contribution richness per note as students moved from Grade 1 to Grade 2 (average 1.14 in Grade 1 and 1.20 in Grade 2), indicating that students in Group A and B make about the same amount of contributions per note. The tendency to make only one contribution type per

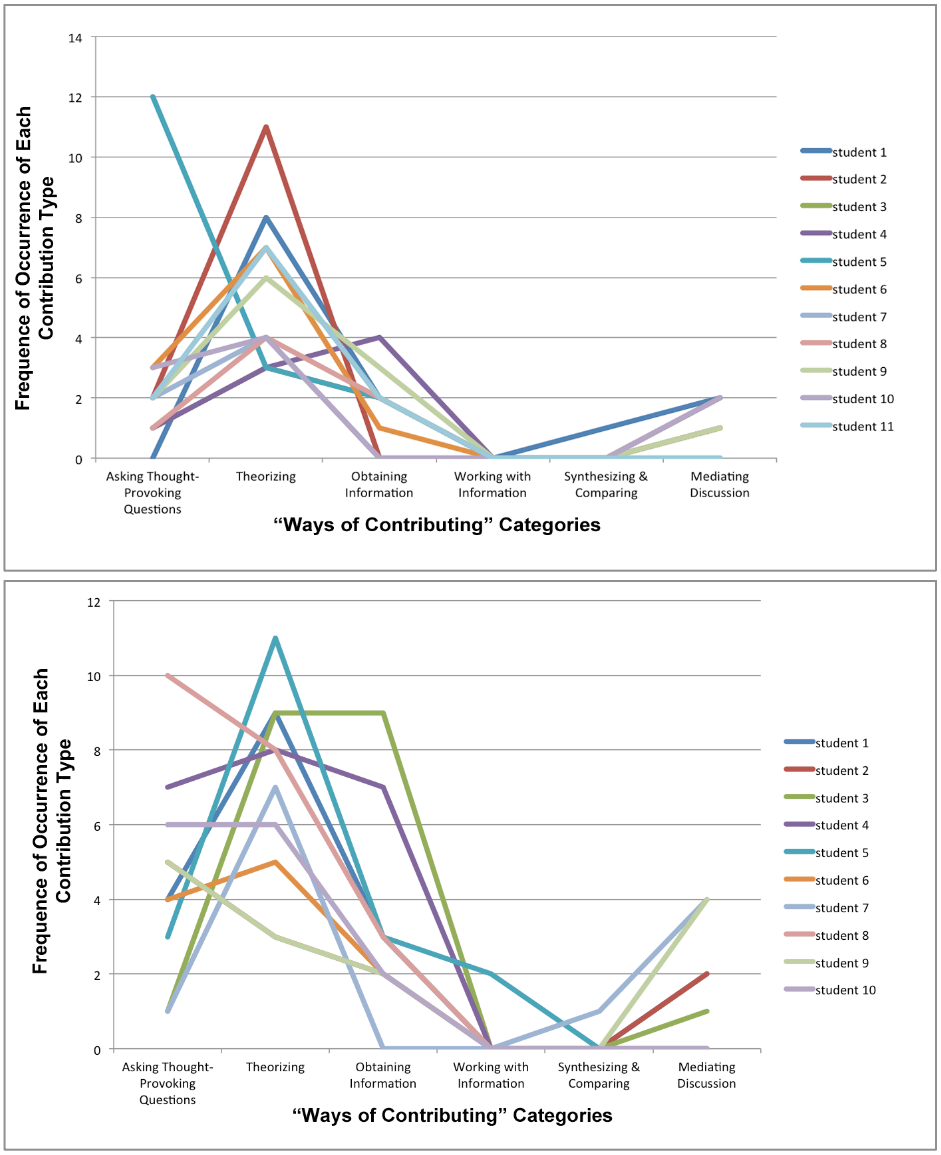


Figure 24. Contribution profiles (*n*) of the online discourse of Group A (top) and Group B (bottom) in Grade 2, 2012.

note average could be due to the writing ability of young students, who tend to write shorter and less complex notes than older students. Moreover, in Grade 2, Group B students made more frequent and diverse contributions than Group A students, but there exists approximately an equal level of contribution richness in two groups, with an average of 1.2 contributions per note.

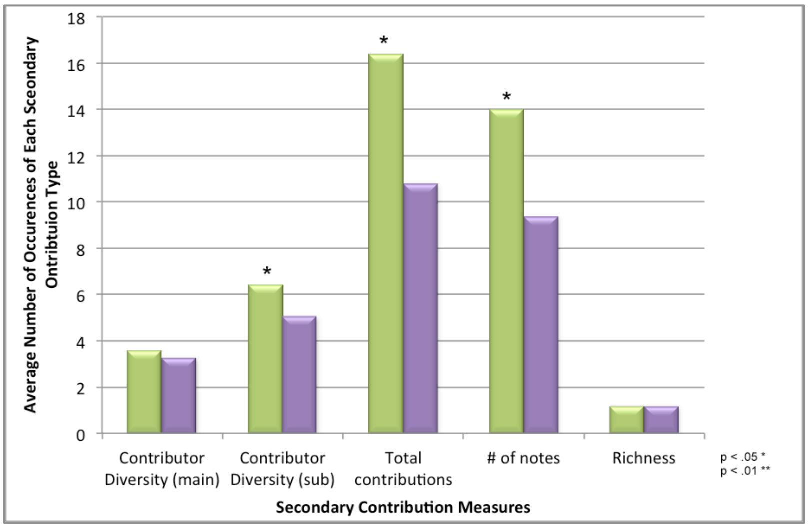


Figure 25. Means (*n*) for secondary contribution measures for Group A and Group B in Grade 2, 2012.

To further investigate effects of the Metadiscourse Tool and metadiscourse sessions, paired-sample *t*-tests were used to compare students' ways of contributing in Grade 1 and Grade 2. As shown in Figure 26, significant differences in the contribution repertoire of Group A Grade 1 and Grade 2 showed the following advances: (a) "proposing an explanation" ($t(9) = 4.64$, $p = .001$), (b) "Obtaining Information" ($t(9) = 3.09$, $p = .013$), and "introducing new information" ($t(9) = 1.96$, $p = .066$). However, Group A contributed significantly more in Grade 1 on the remaining subcategories of "Theorizing"; "supporting an explanation" ($t(9) = 2.58$, $p = .030$), "improving an explanation" ($t(9) = 3.28$, $p = .009$) and "seeking an alternative explanation" ($t(9) = 3.67$, $p = .005$). As shown in Figure 27, significant differences in contribution repertoire of Group B from Grade 1 to Grade 2 showed the following advances: (a) "Asking Though-Provoking Questions" ($t(9) = 3.38$, $p = .009$), particularly "asking explanatory questions" ($t(9) = 2.58$, $p = .029$) and "asking factual questions" ($t(9) = 4.64$, $p = .001$); "Obtaining Information" $t(9) = 2.84$, $p = (.019)$, specifically, "introducing a new fact from a source" ($t(9) = 3.16$, $p = .012$), as well as "proposing an explanation" ($t(9) = 5.09$, $p = .000$). However, the group did significantly better in Grade 1 at "supporting an explanation" ($t(9)$ 3.83, $p = .004$) than Grade 2.

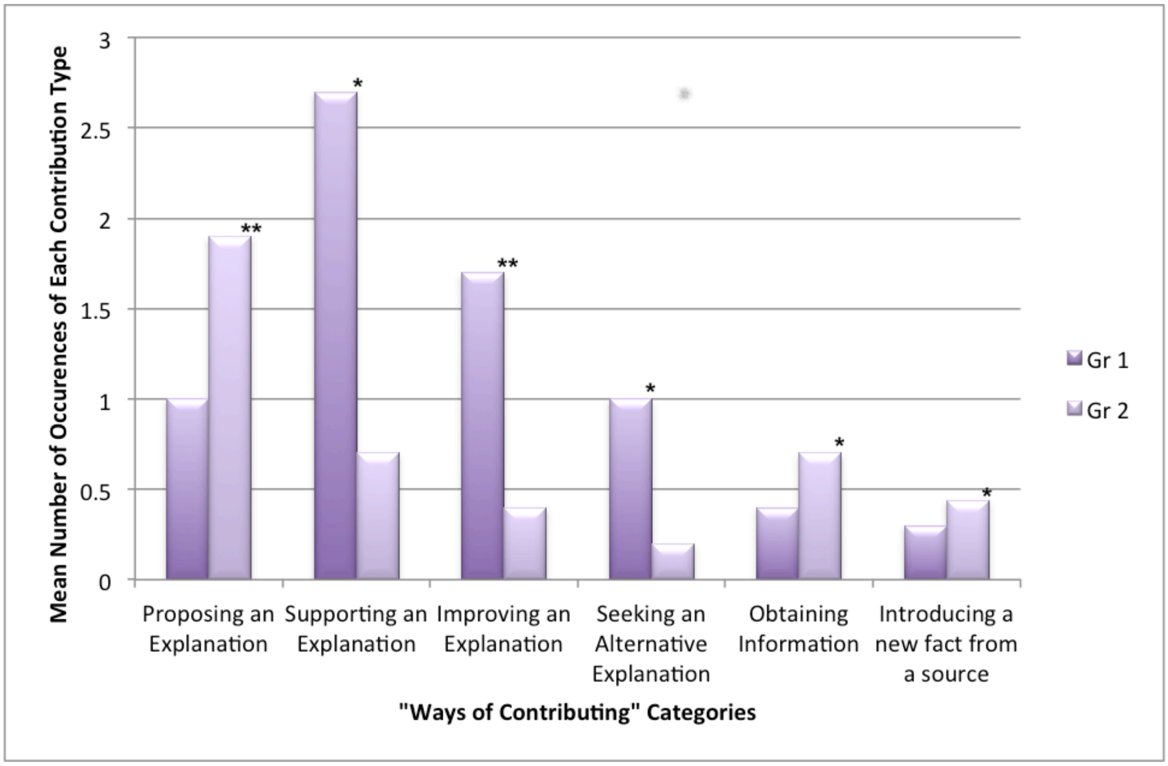


Figure 26. Means (*n*) for contribution types in online discourse that show significant differences in the contribution repertoire of Group A from Grade 1 to Grade 2.

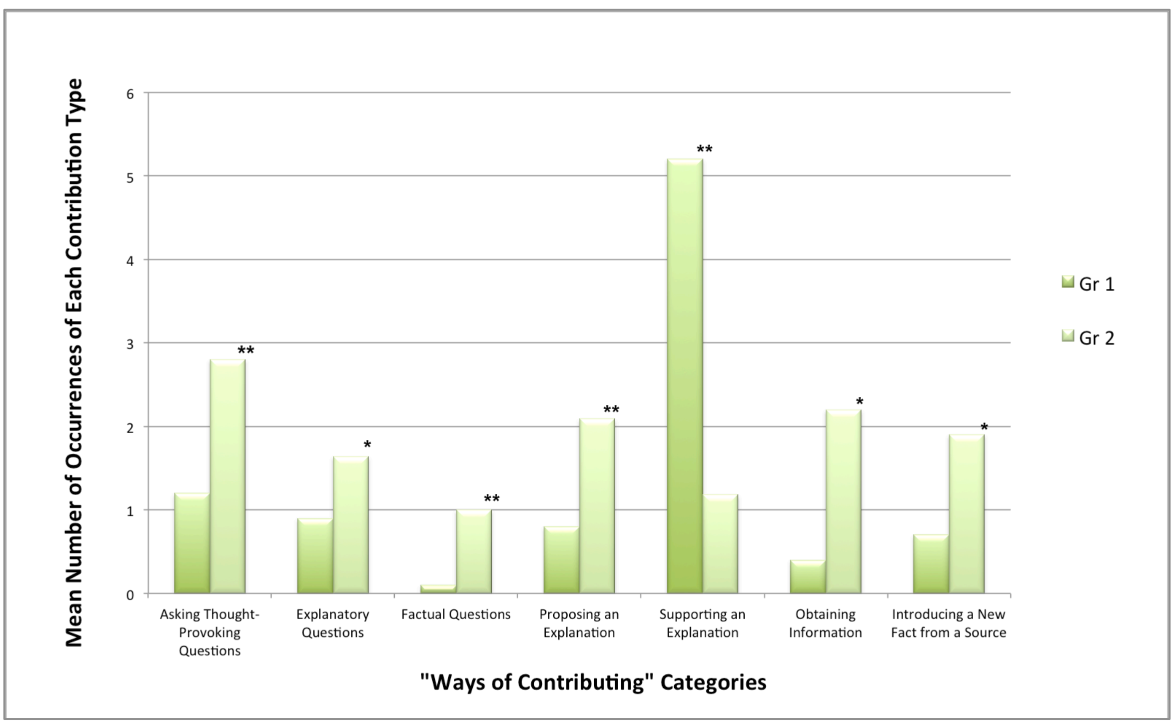


Figure 27. Means (*n*) for contribution types in each group's online discourse that show significant differences in the contribution repertoire of Group B from Grade 1 to Grade 2.

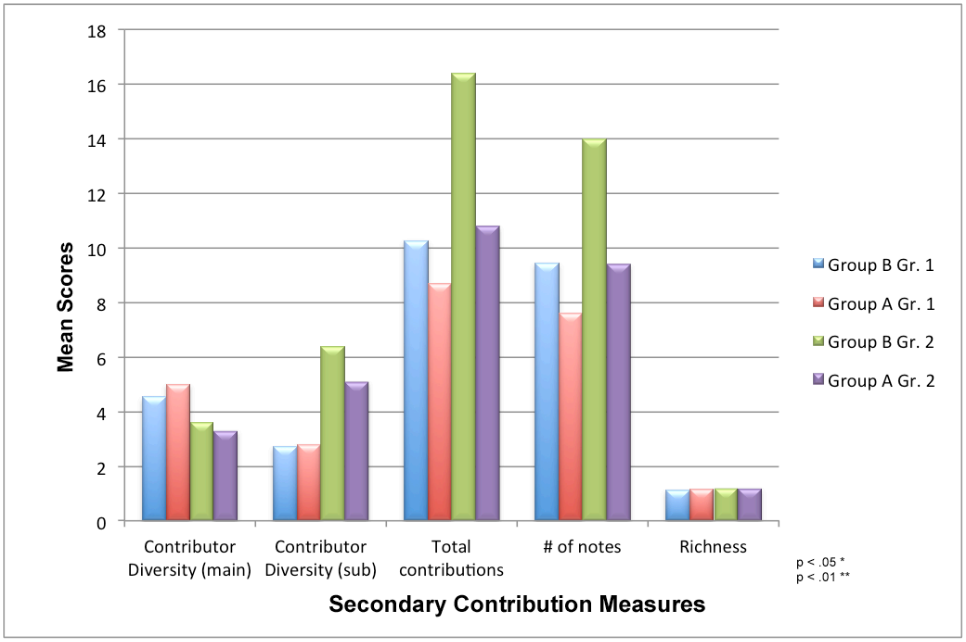
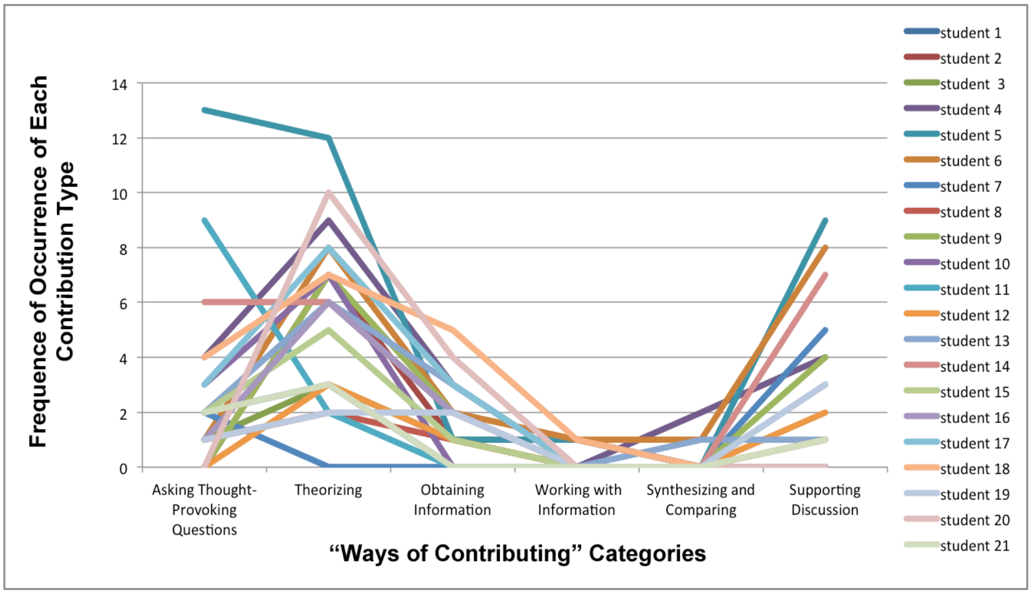


Figure 28. Means (*n*) for secondary contribution measures for Group A and B across Grade 1, 2011 and Grade 2, 2012.

In sum, these findings reveal that reflective discussions seem to help students particularly in contributing more original ideas and integrating new information from sources and research. Furthermore, reflective discussions coupled with formative feedback on the contribution makeup of students' dialogue helped students to ask a variety of questions, in addition to posing initial theories and consulting authoritative sources. However, results also suggest that the important work of supporting existing theories and seeking out alternative ideas can give way to other contribution modes when these are emphasized in group discussion—in this case, Group A's engagement in important subcategories of "Theorizing" decreased as contributions in "Obtaining Information" increased. While students in both Group A and Group B discussed the importance of "Obtaining Information" in group efforts to advance knowledge, students in Group A were not exposed to feedback that could help them see and discuss all the different kinds of contributions they were, or were not, making to their shared dialogue throughout the course of their inquiry. As the driving force of explanation-seeking dialogue, student engagement in "Theorizing" and its corresponding attributes is vital. In this research, it is certainly not desirable for students to lose incentive for theorizing work and improving their own ideas to becoming preoccupied with introducing information from authoritative sources. The goal is to broaden students' contribution repertoire, not sacrifice one contribution type for another. This result represents an important design consideration for the second study iteration—how to ensure a "golden balance" between encouraging increased engagement with targeted contribution types in tandem with broader participation in a diverse set of ways of contributing. Since Group B's performance on attributes of "Theorizing" were not lessened to the same extent, it appears that exposure to feedback that helps students gain a sense of the contribution makeup of their discourse helps them to keep momentum in building ideas while concurrently expanding their contribution repertoire.

5.4.2 Did the experimental class contribute more diversely than their peers in the previous year?

In order to help rule out other general developmental factors for the expansion of contribution repertoire, an analysis of variance (one-way ANOVA) compared three groups: Group A, Grade 2012, Group B Grade 2, 2012, and their predecessors, Grade 2, 2011. Results showed significant differences among the groups on "Obtaining Information" $F(2, 39) = 3.49$, $p < .05$, as well as two contribution subcategories, particularly "proposing an explanation" $F(2, 39) = 3.49$, $p < .05$), and "reporting experimental results" ($F(2, 39) = 3.29$, $p < .05$). As for secondary contribution measures, significant differences were found for contribution diversity on the main categories ($F(2, 39) = 9.71$, $p < .001$) and on the subcategories ($F(2, 39) = 4.02$, $p < .05$).



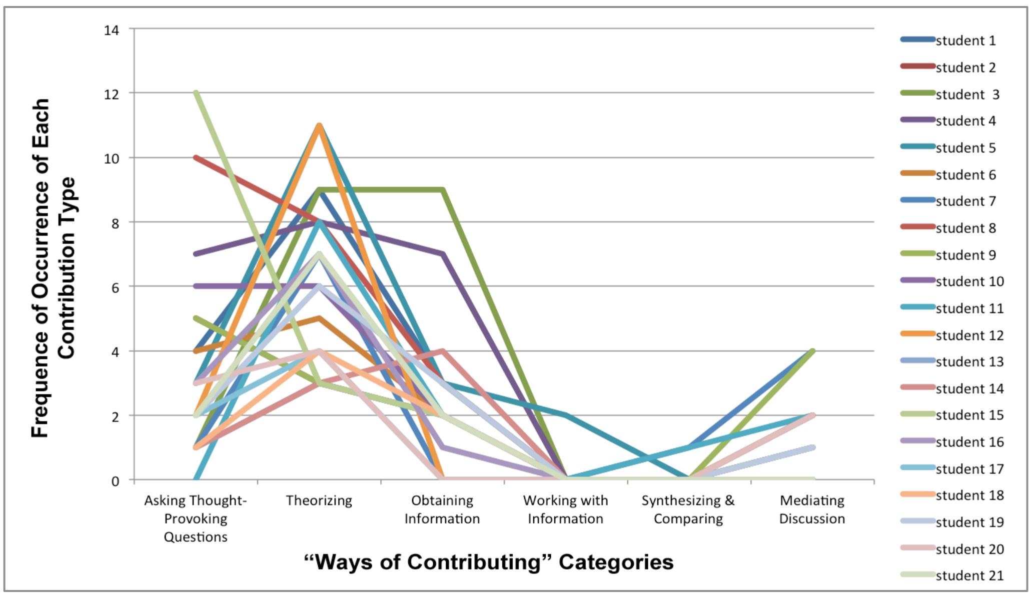


Figure 29. Contribution profiles (*n*) of the online discourse of the Grade 2, 2011 (top) and Grade 2, 2012 (bottom) classes.

Post-hoc tests (Tukey HSD) show that Group B performed better than the Grade 2, 2011 class on the following contribution types: "Obtaining Information" ($p < .05$, Cohen's $d = 1.74$); "proposing an explanation" ($p < .05$, Cohen's $d = 1.83$), as well as "reporting experimental results" ($p < .05$, Cohen's $d = 0.30$) (see Figure 30). These findings support the notion that

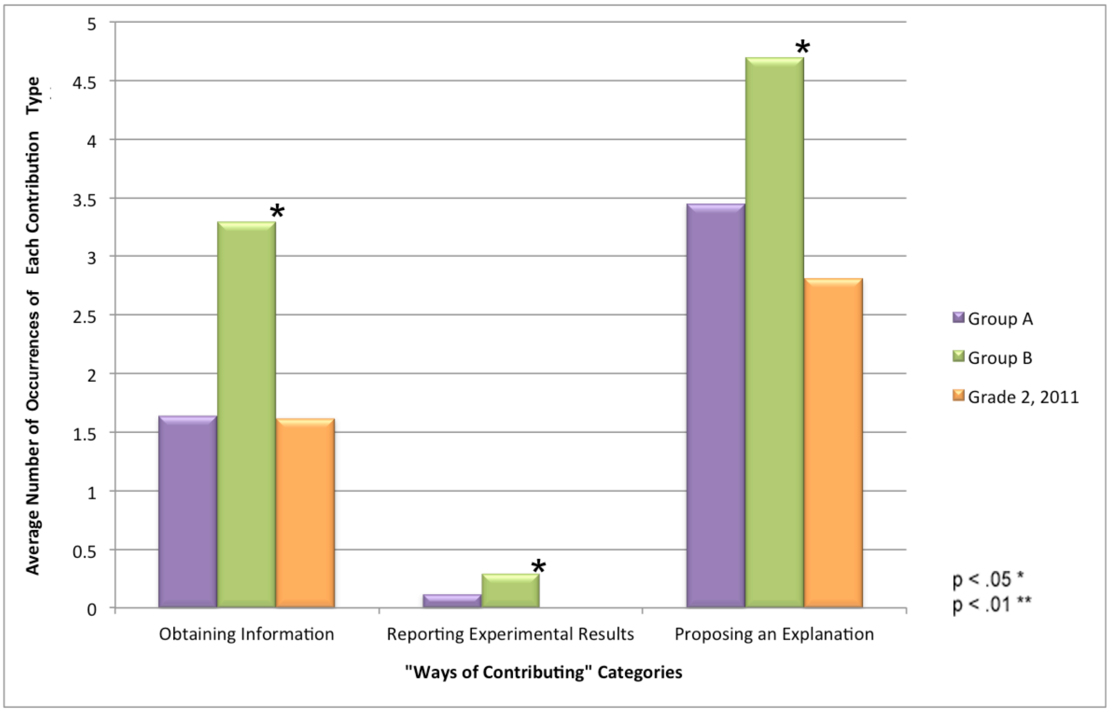


Figure 30. Means (n) for contribution types in online discourse showing significant differences across three groups in Grade 2, 2011 and Grade 2, 2012.

metadiscourse sessions can help students increase performance in regard to posing original theories, and that the explicit discussion of contribution types such as “Obtaining Information”, facilitated by the Metadiscourse Tool, can help students expand repertoire in targeted areas.

In addition, post-hoc comparisons showed that the 2011 class outperformed both Group A ($p < .01$, Cohen’s $d = 1.78$) and Group B ($p < .01$, Cohen’s $d = 1.78$) on contributor diversity for the main categories. The 2011 class also did better with respect to subcategories, outperforming Group A on this measure ($p < .05$, Cohen’s $d = 2.43$) (see Figure 31). This finding challenges our hypothesis that exposing students to a visualization that charts the contribution makeup of their dialogue will help them expand their repertoire. However, this difference can be attributed in part to the individual capacity of students in each class. For example, the contribution diversity of students in the Grade 2, 2011 class was higher for both the main

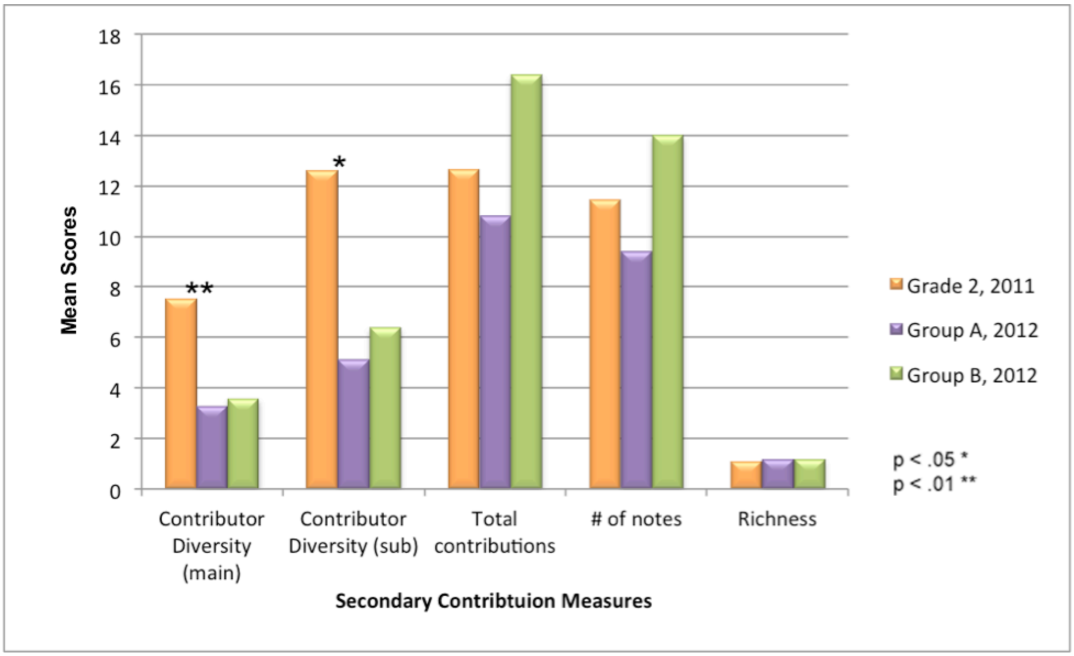


Figure 31. Means (*n*) for secondary contribution measures across three groups in Grade 2, 2012 and Grade 2, 2011.

(*M* = 5.38, *SD* = 1.86) and subcategories (*M* = 7.52, *SD* = 3.08) than the Grade 2, 2012 class, who scored a lower means for both main (*M* = 5.36, *SD* = .86) and subcategories (*M* = 7.64, *SD* = 1.49). It is notable to mention that there were eight students in the 2011 class that showed distinctly higher level of diversity in their contribution repertoire as compared with all the remaining 35 students from both classes combined (see Figure 32). This finding suggests that further research into the particular ways that individual student capacities feed into group level dynamics can shed light on the efficacy and impact of the Metadiscourse Tool; for instance, do particular students take on distinct contributor roles? How do the contributor profiles of students with particularly diverse repertoires compare with others that are less diverse? What roles do the contributions of each student play in carrying the community knowledge forward? Such research is beyond the scope of this thesis, however the issue represents an interesting direction for extending this research.

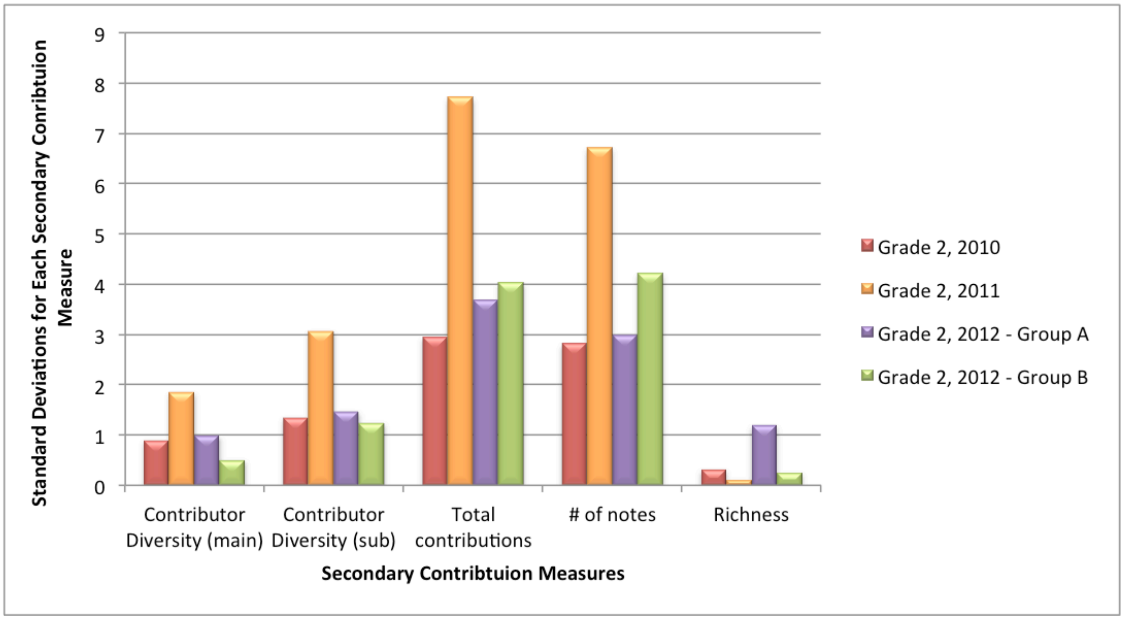


Figure 32. Standard deviations (*SD*) for secondary contribution measures across three groups Grade 2, 2012 and Grade 2, 2011.

5.4.3. Ways that Grade 2 students were "Obtaining Information" in their explanation-seeking discourse

In this section, I highlight some examples of student work in order to supplement quantitative results, and to provide a more comprehensive look at the ways they contributed by "Obtaining Information" to their collective discourse. As described in the study design, the teacher and I had hoped to boost students' engagement with "Obtaining Information" and "Working with Information" as they pursued their Knowledge Building work on birds and salmon. The graphs depicted in Figure 33 represent all the contributions that students were making during their pursuit to understand "how birds fly." As displayed by the graphs, students increased their use of the "new information + source" scaffold from two to 15 during the course of the inquiry. Growth in use of the "this information is important because" scaffold, however, is not so marked, totaling only three uses. This observation corresponds to the absence of quantitative findings indicating significant increases in the experimental class with respect to "Working with Information."

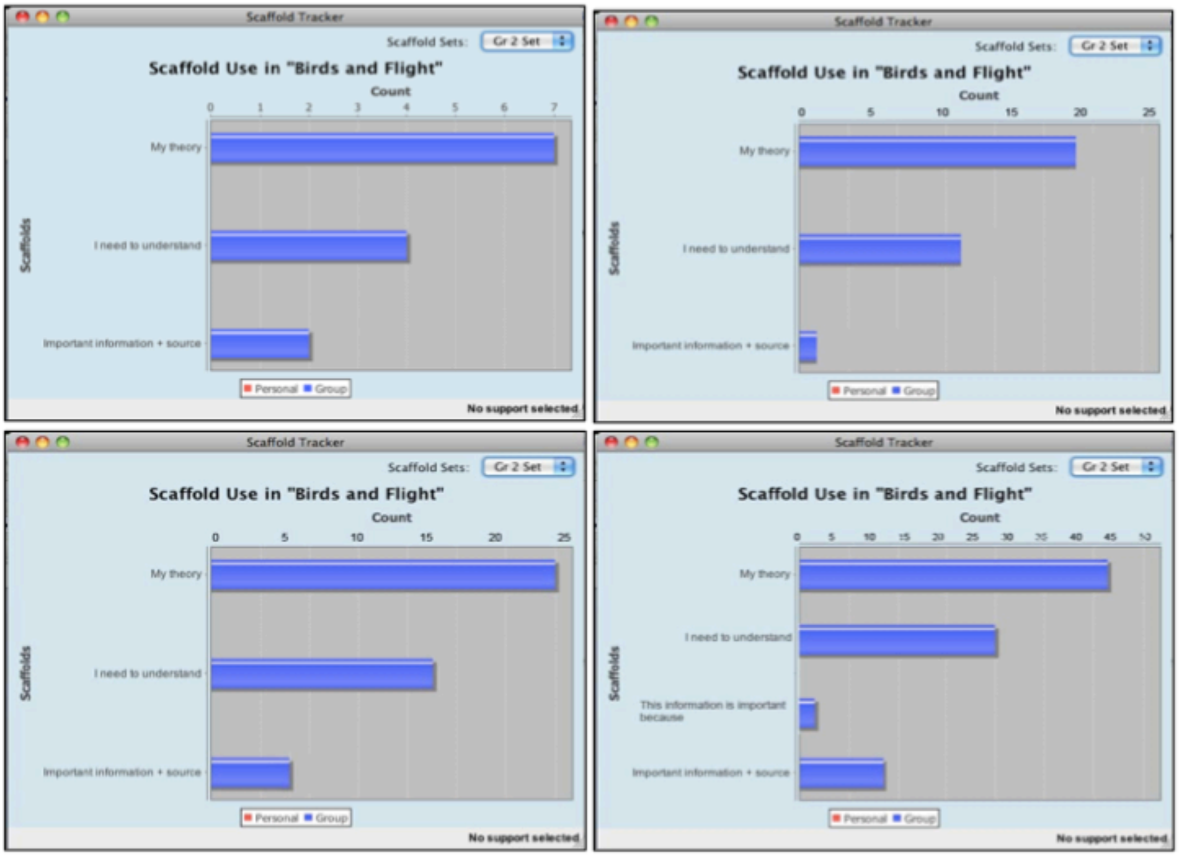


Figure 33. Graphs made by the Metadiscourse Tool showing growth in scaffold use over time.

Reasons for the relative failure of this particular scaffold are discussed in Section 5.5. However, at this point, I focus on exploring examples from the online discourse and the group discussions that showcase the different ways that students were successfully "Obtaining Information", such as contributing information gleaned from sources, experiments or empirical observations made throughout their inquiry. These examples also illustrate the extent to which work on and offline are interconnected.

For instance, around the middle of the study on birds, "how birds fly" became a popular problem of understanding. During a "KB Talk" that focused on discussing readings from an authoritative source on birds and flight, a young girl stated explicitly that she was going to write a note about "drag" after the teacher had read a description of the term out loud to the class. Her note, though simple, represented her own articulation of the concept: "*Important information + source: when a bird is dragging their feather it is slowing itself down. It is called a drag.*" Similarly, having identified "redd" as an unknown word on an "Expert Words" visualization during a Metadiscourse discussion, a young boy looked up the meaning of the term in the index of a classroom textbook and added this note: "*Important information + source: redd means a shallow nest dug into gravel by a female salmon.*" While these examples represent simple statements of fact, the students were motivated to engage with the terms on their own and performed the important service of introducing relevant and unknown terms in to the community dialogue. In some cases, having been introduced to the discourse, key terms incited further questioning and became an increasing presence in students' lexicon (see Sections 5.4.5 and 6.6. for a more detailed discussion on examples of this).

Likewise, students were also careful to report information they collected from their research and activities into the online discussion. For instance, students frequently contributed information they gleaned from observations they made of the salmon eggs that incubated and hatched in the classroom tank. The following examples illustrate some of these contributions: "*Important information + source: when we let go of the salmon I observed that some salmon died and some didn't"; "Feb. 23. 4 fish have already hatched. I checked"; "My theory: Salmon are a circle when they are in their egg.*" Here, students are making and communicating careful observations in their writing—for example, by using appropriate scientific terminology ("I observed"), as in the first note, by carefully documenting the particular date of their observation and tallying specific numbers, as in the second note, or by giving careful descriptions of what they are seeing, as in the third note. In addition to recording empirical observations, students also made efforts to address questions with information they acquired from expert sources. For instance, in response to a classmate's question, "*why are salmon orange?*" a young boy writes:

"*Important information + source: Salmon are orange because they are camouflaged against their enemies. Chris Robinson told us that*" (Chris Robinson is the Atlantic salmon planning biologist that brings the salmon eggs to the class).

These samples of student work illustrate the different ways the 2012 class participated in "Obtaining Information" in their shared dialogue, providing encouraging evidence of young students' capacities to engage with varieties of this contribution type in the larger effort to build theories addressing their own problems of understanding. The discussion that follows provides another qualitative layer to the observations made above by exploring the ways that students applied the facts and information they introduced to the discourse to improve their own ideas.

5.4.4 Did the experimental class achieve greater knowledge advancement?

It was predicted that students who engaged in metadiscourse and received feedback via the Metadiscourse Tool would advance their knowledge to a greater extent than students who only engaged in metadiscourse sessions; another hypothesis was that students who participated in metadiscourse dialogue would exhibit greater knowledge advancement than students who did not receive any treatments at all. To explore this possibility, a series of comparisons was conducted between Groups A and B across Grade 1, 2011, as well as within Grade 2, 2012, and also between two distinct Grade 2 classes, namely the 2012 and 2011 classes. First, a paired-sample *t*-test comparing the mean "scientificness" and complexity scores of the Grade 2, 2012 class with their scores when they were in Grade 1 showed a significant improvement on both "scientificness" ($t(19) = 5.59$, $p = .000$) and complexity ($t(19) = 3.63$, $p = .002$). Both Group A and Group B performed better in Grade 2 on "scientificness" ($M = 2.56$) and complexity ($M = 1.71$) than in Grade 1 ($M = 1.78$) and ($M = 1.28$), respectively (see Figure 34). To help rule out whether increases in performance were due to development factors corresponding with grade

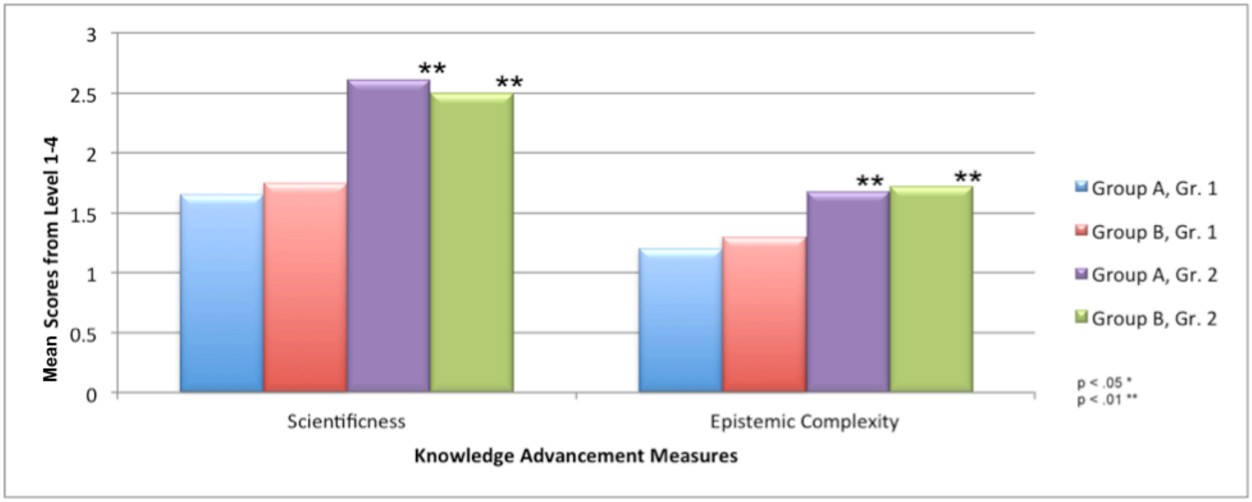


Figure 34. Means (*n*) for knowledge advancement scores for Groups A and B in Grade 1, 2011 and Grade 2, 2012.

level, we triangulated these findings with tests that compared the two groups in Grade 2, 2012 as well as with the whole Grade 2, 2011 class. An independent samples *t*-test comparing the mean scientificness levels of ideas between the two subgroups in the Grade 2, 2012 class showed no significant difference for "scientificness" ($F(19)= .091$, $p = .929$) and complexity ($t(19)=.793$, $p = .438$). However, a one-way ANOVA was conducted to compare performances between Group A and B of the Grade 2, 2012 class with the whole Grade 2, 2011 class. Findings showed significant differences with respect to both "scientificness" ($F(2, 38) = 11.14$, $p < .001$) and complexity ($F(2, 38) = 3.37$, $p < .05$), with post-hoc tests (HSD) revealing that both subgroups from the Grade 2, 2012 class performed better than the Grade 2, 2011 class on "scientificness" ($p < .01$, Cohen's $d = 0.59$) and "epistemic complexity" ($p < .05$, Cohen's $d = 0.39$), respectively (see Figure 35).

So, although the analysis showed no significant difference between subgroups in the Grade 2, 2012 class with respect to "scientificness" of notes, it did reveal significant differences between the two consecutive years (Grades 1 and 2) of the same students, as well as the two Grade 2 classes in two consecutive years (2011, 2012). These findings imply that engaging

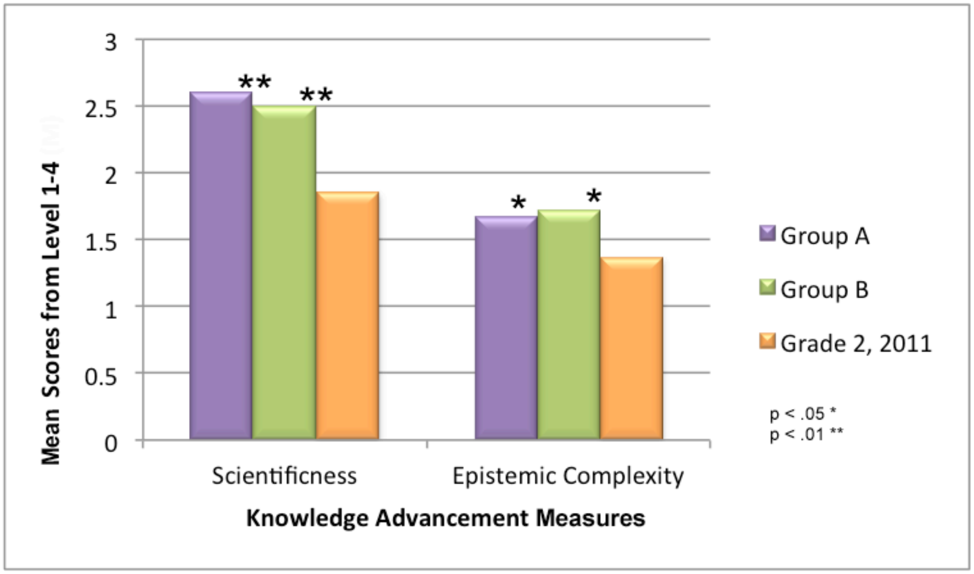


Figure 35. Means (*n*) for knowledge advancement scores for Grade 2, 2011 and Grade 2, 2012.

students in repeated metadiscourse discussions and exposing them to visualizations produced by the Metadiscourse Tool can have a significant impact on knowledge advancement of students and an overall positive effect on their Knowledge Building work.

5.4.5 Ways that the Grade 2 students were advancing community knowledge

The nature and extent of students' knowledge advancements can be explored in part by comparing two similar "inquiry threads" (Zhang et al., 2007) that emerged in the online discourse of both the 2011 and 2012 Grade 2 classes. The inquiry threads examined here engage the question "how do birds fly," which emerged as a particularly interesting problem of understanding for both Grade 2 classes. The question was asked repeatedly in the 2012 discourse, and was predominant enough amongst the 2011 class that they created an entire view dedicated to it. With respect to the 2011 class, the inquiry on birds and flight began when one student asked: "*how come some birds can fly but others can't?*" Students offered a number of theories in response to this question, including the idea that birds need hollow bones in order to fly; some birds are better at swimming and running; birds that are too heavy cannot fly; and birds that get their wings wet or have short wings cannot fly. Students supplemented these ideas with pieces of information, such as: "*Important information + Source: some birds have more wings than other birds,*" or "*Important Information + Source: their honeycomb bones make light and it helps them fly.*"

During this discussion, students responded to each other's contributions and questions in impressive ways. For example, the following example depicts one student's response to the question of whether birds need hollow bones to fly: "*My Theory: I don't think so. I only know two birds that have honeycomb bones. Ostriches don't fly so they don't need that kind of bone. But penguins maybe do. When they jump in the water they can fill up their body with air and float. When they dive, they get rid of the air.*" As this example shows, this student demonstrates skillful reasoning in his struggle to understand the role of bone structure to particular birds' behaviours and capacities for flight. Although his speculations raise some interesting issues that implicate the role of environment and adaptation to a particular birds' behaviour, the wider conversation does not turn in this direction. Rather, the dialogue shifts slightly from the role of bones to the role of feathers in enabling flight when one student proposes that, "*feathers help birds to fly.*" This discussion around feathers represents the end of the inquiry, which concludes with another student subsequently asking: "*how can birds fly with lots of heavy feathers on?*"

In the case of the Grade 2, 2011 class, while the students proposed a range of important theories addressing the central question "how do birds fly?" they did not elaborate on these theories to probe more specific questions—for instance, how do feathers help birds fly? How or why might shorter wings impede flight?, etc. Although students did not generally sustain work on existing theories by further questioning, they did raise a number of other thought-provoking questions, such as "*how can birds fly for so long?*" or "*I need to understand: how can birds glide if they are not flapping* [their wings]?" They also introduced a number of interesting facts that could inspire research which could shed light on these same questions; for example: "*My Theory: birds of prey glide in circles on thermals to climb without wasting energy.*" As these examples show, the 2011 class expressed authentic interest in investigating the problem of how birds fly, posed a number of promising questions around flight, and introduced some provocative and relevant facts into the group dialogue. However, the discourse was dominated by questions around the problem of birds and flight, with many of these left unaddressed. The conversation could have benefitted from more theorizing effort around these questions so that ideas could be connected and theories improved.

In the 2012 class, the question of how birds fly also intrigued students, and had a notable presence in the online discourse. In this class, students began their inquiry around this question by offering ideas that were largely similar to those from the 2011 class, such as: birds' wings help them to fly; the wind keeps birds in the air; birds' feathers help them to fly; and, birds can fly because they are light. Over the next couple of weeks, students most often built onto the idea that feathers were important in enabling birds to fly. For example, a student posed the idea: "*My Theory: I think that the design of their feathers helps them to fly.*" Another student built onto this theory by adding a small but useful detail: *"My Theory: The shape of the feather is curvy. That helps it to fly.*" Also, as in the previous year's class, newer, more refined questions emerged from the discourse as it progressed; take for example, this young girl's question and corresponding theory about a specific aspect of flight: "*I need to understand: how birds take off when they are going to fly? My Theory: is I think they just lift their wings and flap up and down, and with their tail feathers they can go left, right, up and down and that's how they steer, the wings help them take flight and the tail helps them steer*." Another student tries to explain the phenomena of flight by making a comparison to another flying object that operates in ways he might be more personally familiar with: "*My Theory: birds fly because they are light and there feathers are like* *a parachute*" The online discourse also showed students using the new words they encountered in the Word Cloud feedback into their comments, as these two examples show: "*My Theory: bird feathers are aerodynamic so they can fly fast"; "Important information + source: when a bird is dragging their feather it is slowing itself down. It is called a drag*" These novel terms also inspired new lines of questioning, such as "*[I need to understand] what do birds use to make a drag?*", that could help students understand the puzzling problem of how birds fly. In this case, the students' sustained focus on the role of feathers in enabling flight helps them to speak more specifically about particular attributes such as a "curvy design," incorporate relevant terms like "steer" and "drag," and open up their discourse to new paths by probing new concepts—for instance, the final question about "what makes a drag" calls for exploration of the interplay of air currents and wind with the design of feathers and wings. While the Grade 2 students' actual conversation does not extend to include these sorts of considerations, the fact that their own discourse has led them to such a point reveals that these students were moving their dialogue in productive and promising directions.

In general, both classes demonstrated achievements that corresponded to the curriculum expectations and outcomes, such as fruitfully investigating characteristics of different animals, exploring the ways animals grow and change, and using appropriate vocabulary in their writing. Both classes also successfully populated their discourse with a number of thought-provoking questions, a range of ideas, and relevant facts. However, the 2012 class spent more time addressing the questions they posed by building onto each other's ideas, and thus demonstrated a more diverse and sophisticated set of theories to the question of how birds fly.

5.5 Could young students engage in productive metadiscourse?

In this section I highlight specific examples of student dialogue made during metadiscourse sessions. Because students' spoken conversation does not constitute hard data for this study and is thus not subject to quantitative analysis, it is important to include a discussion highlighting the benefits of this kind of shared dialogue on students' capacity to engage diversely in explanation-seeking dialogue. In what follows, I discuss various points of interest regarding the metadiscourse sessions that took place with students, including students' interpretation of feedback, as well as discussion around scaffolds and discourse types. I also comment on ways young students contribute to collaborative metadiscourse, in comparison to their written dialogue.

i) *Interpreting feedback:* For this study, the teacher guided students through an introduction to the visualizations produced by the Metadiscourse Tool as well as the Word Clouds. Students understood that the Metadiscourse Tool tracked their own scaffold use, and were able to comprehend quite quickly that the Word Clouds constituted words from their own discourse as well as those of "expert" sources. They were also able to read the visual markers of the word clouds with little instruction, pointing out that the larger the word, the more frequently that word is being used in the source data. Students actively engaged with both types of visualizations, often reading the data presented out loud, or walking up to the visuals to gesture and point towards particular areas of interest (see Figure 36).

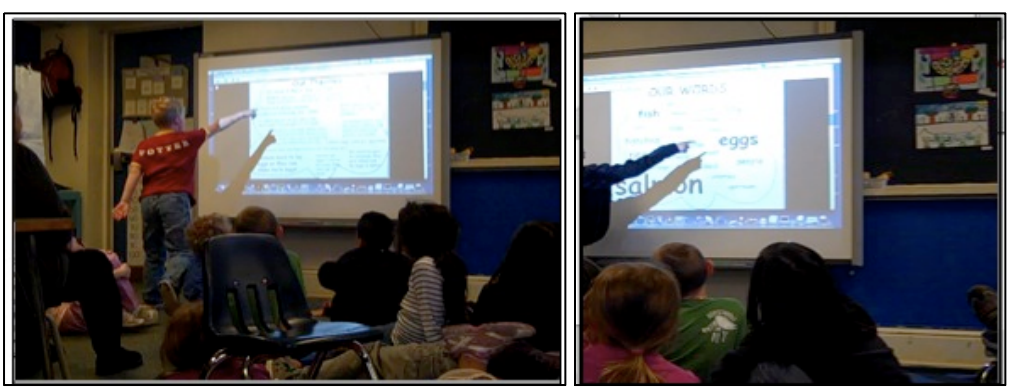


Figure 36. Student gesturing towards words on the Word Cloud feedback visualizations while reading out loud.

ii) *Discussing scaffolds:* An important object of the metadiscourse sessions was to boost students' capacity for "Obtaining Information" and "Working with Information." To this end, we offered students the choice of one of two new scaffolds designed to have students think about the facts they introduce into the dialogue. As described, the classroom teacher introduced the new scaffolds during a metadiscourse discussion in order to see how the students responded to each version. The following is an excerpt of the discussion with the experimental group about these two new scaffolds:

> *Teacher:* "What does that tell us? 'This information is important because'… Why would we need this?"
> *Student A*: "Say if for example I read a book and then I went onto KF, to write a note, I would go on to "Important Information + Source," but then if someone came on and read my note, and they said 'why did you put it on?' So I would write, why you put it on."
> *Student B*: "So let's say if, lets' say we had a really special theory that a lot, that's really, really, important, then you would put it on 'This information is important because' because it says 'important' so if its important then you put it on this."
> *Teacher*: "So how would you know it's important… it would be important information that you wanted to share with other people and it connects to other notes or would it just be your note, and it says "this information is important because"…
> *Student A*: "Well you can add it on to other people or you can just use it."
> *Teacher*: "How could "This information is important because" help you know more about birds and flight?"
> *Student C*: "Well, if some people get something out of a book and put it in "Important information + source" and you read it and you really like that idea you can write about it because you like it or you think it's interesting."

In this discussion, *Student A* demonstrates an understanding that the new scaffold is asking students not only to introduce but to apply a certain fact to a theory or line of inquiry by explicitly explaining *why* that information was contributed. Other students explain that the new scaffold is most useful for marking a "special," or "interesting" idea, or one that a student "likes" or is drawn to. These comments seem to imply that students are qualifying a fact as important if it connects with their own personal interests, rather than to the needs of a particular group investigation. Student use of this scaffold in practice reinforces this point. Take, for instance, this student's note: "*This information is important because: owls need to live because I like the sound of them screaming in the night. If there was no owls, there would be lots of mice. If there are too many mice, there would be mice pee everywhere and that is bad because the pee has germs*." In this case, the student uses the scaffold to explain his own preferences, and then moves on to discuss an interesting idea related to food webs involving owls and mice. While this example may not be ideal, it is important to recognize that, during discussion, students claimed that the scaffold could be useful for assigning importance to information as well as to people's own ideas, and could offer them a novel mode of contribution that they feel has some use to them. The utility of this scaffold for Design Cycle 2, however, was questioned due to its infrequent presence in the students' dialogue in general, an issue which is discussed further in Section 5.6.2.

The enthusiasm over the scaffold "This information is important because" stood out that much more when compared to the reaction students had to the second scaffold, "This information helps explain." Below are excerpts from a conversation that arose around this version of the scaffold:

> *Teacher:* "…if you guys had a choice, would you … add on to … "This information helps explain" or … "This information is important because."
> *Student A*: "Probably "This information is important."'
> *Student B:* Who else thinks, or would choose "This information is important?"
> *Student C*: "The other one is harder because sometimes explaining something might be harder for you and the other one you just have to say something about what, if you're building on."
> […]
> *Student D*: "It's hard to use "this information helps explain" because it's hard to explain what explains…well, it's pretty hard to explain!"

As these responses show, students do not find this scaffold as accessible as the previous one. However, students did seem to appreciate that explanation calls for a more demanding type of contribution than simply stating a fact or explaining why one might think a fact is important. Studies exploring the different strategies young children employ for reading and summarizing stories and other texts can help shed light on the scaffold preferences the Grade 2 students display here (see, for example, Brown, Day, and Jones, 1983; Brown & Day, 1983). For instance, Brown and Day (1983) show that young students, namely fifth and seventh graders, tend to employ a "copy-and-delete" strategy (Brown, 1981) when attempting to summarize a text in their writing; that is, students are able to identify both important and less significant portions of a text, but in their retelling of that text, tend to either repeat significant sections verbatim or delete less important ones outright. While elementary aged students experience difficulty condensing, transforming and paraphrasing information, the effective use of more complex strategies for rearticulating and summarizing information only begins to appear more consistently at the secondary or postsecondary levels. Thus, the fact that the Grade 2 students in this study preferred the scaffold that called for a more straightforward application of information from external sources is consistent with the common strategies employed by young students for summarizing and retelling information as described in the studies referenced above.

Needless to say, the immediate dislike of the second scaffold, "This information helps explain," was a lesson for both the teacher and myself. While the teacher and I admittedly had reservations about this particular version, the process of attempting to compose and implement an effective new scaffold design proved difficult. Although scaffolds appear to be very simple and straightforward, they are powerful tools to support complex and extremely important knowledge building processes; if they fail to be accessible to students than they will likely never become an organic part of their discourse. Eliciting student feedback about these supports served the dual purpose of getting students in the habit of reflecting on important contribution types and

on the scaffolds themselves, as well as helping the teacher and I make critical design choices.
iii) *Making diverse contributions:* As quantitative analysis shows, metadiscourse sessions proved valuable for helping students deepen their understanding of various concepts related to the life systems of birds and salmon. In practice, during these reflective discussions students were often able to verbalize their ideas in ways not evident in their written contributions. Take, for example, a young girl's response to a question that remained unanswered on the database but inspired discussion when shown on a "Our Questions" word cloud visualization during a metadiscourse talk: "I have the answer to the question about why salmon go to the sea at all…like, birds they migrate, and so do salmon. When they migrate to the sea that's migrating from the rivers because the rivers get colder in the winter and sometimes they can freeze but the ocean can't freeze so they go to the ocean and then when it's time, they go back because in rivers there's lots of rocks so it's easier for them to hide and they can lay their eggs and not a lot of things can see them.. Making broad connections between the life cycles of birds and salmon, as this student does here, is a type of contribution that remains absent from the online discourse but comes out quite effortlessly in a discussion in which students are invited to recall and reflect on their ideas.

Another example of students engaging in contribution types during whole class metadiscourse sessions that were infrequent or rare in the online discourse involved a group of students "proposing an experimental design" to help investigate the mysterious death of one of their classmate's pet frogs. Students began this conversation by reflecting on the questions they had concerning the survival rates of the baby salmon growing in their classroom tank. They began to talk about how odds for survival could be tested if the salmon would be placed in different environmental conditions. Conversation turned to the question of whether the baby salmon would be able to survive in a tropical fish tank another student had at home. This incited a question by one little girl about the death of one of her two pet turtles. According to this student, when both turtles were alive, one of them would typically eat all the food she fed to them, while the other was left scrounging for leftovers. When one turtle mysteriously died, the girl was at a loss to explain why. She theorized that the turtle that died was the one that ate too much food, and so must have gotten sick. However, she remained perplexed and admitted: "I still have no clue [which turtle died] because I'm pretty, pretty sure that the one that died was the one that ate all the food and I don't still understand why!"

This statement prompted other students to propose experimental designs that could help her distinguish between frogs to discover which one died and why. As one classmate suggested, "Before it died you could put stickers on them, like 1, 2, 3, 4… and you could watch it." Another student proposed an experiment for both the classroom salmon and her classmate's frogs: "We don't change the temperature and we leave it really cold, and if [the fish] don't die, that would be good, and if they die, then we know we'd have to figure out the temperature…and then we'd have to figure out if other things need different temperatures, like [the] frogs, we can put it in the same type of water as the fish, but I think if we just put a little [water] in the plants would eat it all up. Maybe one of the frogs died because of the temperature?" While no students made written contributions that proposed experimental designs or suggested improvements to proposed designs, the students were quite capable of generating ideas for experiments that could help them solve puzzling problems for which they could not generate satisfactory theories.

This example suggests that, in addition to the standard set of Grade 1-2 scaffolds used in this particular school, the introduction of other scaffolds, such as "we need an experiment to," could potentially be phased in for younger students as they progress in their inquiry during both regular group "KB talks" and reflective discussions. Indeed, as these cases show, students were able to contribute to the metadiscourse talks in ways that had yet to be seen in their written discourse, including making broad connections across units and planning experimental designs.

5.6 Triangulating data: Comparing the Experimental Grade 2 Groups with Groups in the Primary Study.

In this section, I present results of analyses conducted that compare the Grade 2, 2012 class with existing data collected from the initial study reported in Chapter 3. I first assess the performance of the experimental Grade 2 class against both the Grade 2, 2011 and Grade 2, 2010 classes. I then compare the discourse of the Grade 2, 2012 class with that of the Grades 1, 3, 4, and 5/6 classes from the 2010 school year to explore if the experimental Grade 2 students performed better than their counterparts from 2010 with relation to the other elementary grades. Because analysis from the classes in 2010 was only conducted on one inquiry unit (the first inquiry of the year), I only assess the first Grade 2 inquiry (the Bird Study) in this comparison.

5.6.1 How do three different Grade 2 class compare with respect to contribution and knowledge advancement measures?

Both the study reported here and the initial study detailed in Chapter 3 called for identical data analysis on three consecutive Grade 2 classes (2010, 2011, 2012). So, data was triangulated from all three classes to determine whether any patterns or consistencies with the results could be detected. One-way ANOVA comparisons were conducted on contribution and knowledge advancement measures between the four groups – the 2010 class, the 2011 class, and Group A and Group B from the 2012 class. While this current study compared the work of the 2011 and 2012 class over a full year, which included two inquiry units, data for the 2010 class only consists of the students' first inquiry unit that took place over the first half of the year. Thus, in these comparisons, only the first inquiry units in all three classes are compared. As described, the 2010 class studied Trees and Forests, and both the 2011 and 2012 classes studied Birds. All were science units that fit under the "Understanding Life Cycles" curriculum stream.

Results for analysis on the "Ways of Contributing" categories showed a significant difference on the following categories: “Asking Thought-Provoking Questions” $F(3, 61) = 3.60$, $p < .05$; “Theorizing”, $F(3, 61) = 4.88$, $p < .01$; and last, “Obtaining Information” $F(3, 61) = 5.88$, $p < .01$. No significant differences were found for “Working with Information,” “Synthesizing and Comparing,” or “Supporting Discussion” (see Figure 37).

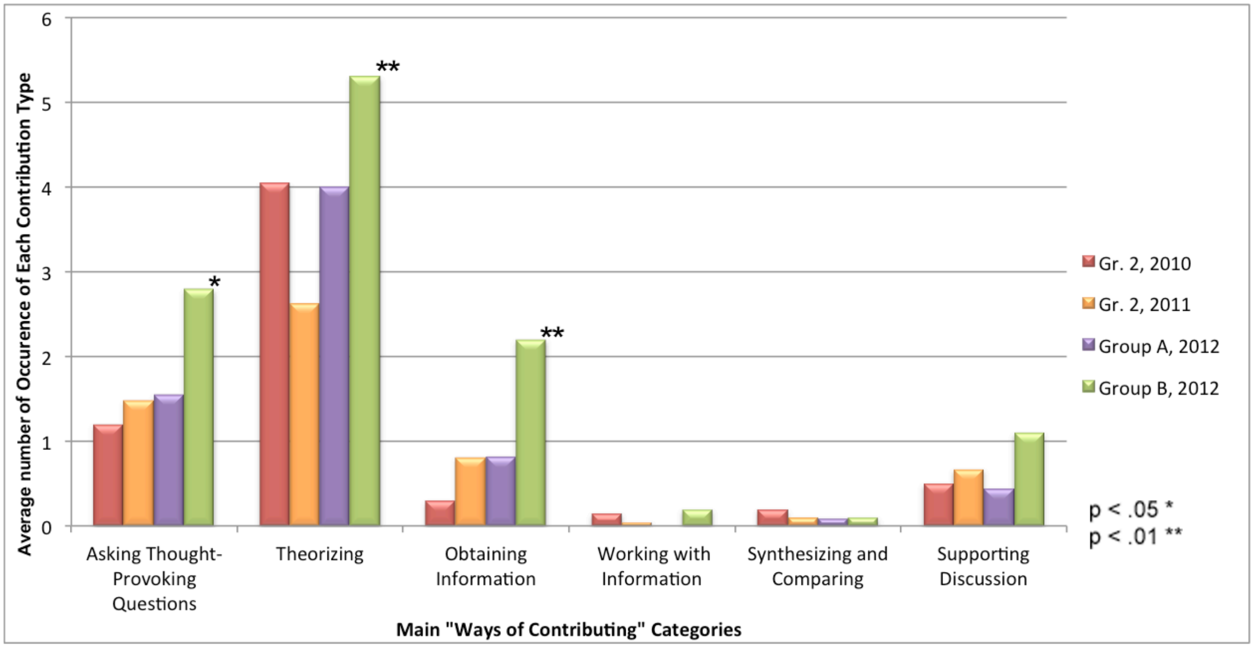


Figure 37. Means (*n*) for main contribution types in online discourses across four groups.

Post-hoc tests (Tukey HSD) show that Group B from 2012 contributed more to “Asking Explanatory Questions” than the 2010 class ($p < .01$, Cohen’s $d = 1.64$) and the 2011 class ($p < .05$, Cohen’s $d = 1.33$). This group also performed better than the 2011 class on “Theorizing” ($p < .01$, Cohen’s $d = 2.49$). Group B contributed significantly more to “Obtaining Information” than the 2010 class ($p < .01$, Cohen’s $d = 1.40$), the 2011 class ($p < .05$, Cohen’s $d = 1.14$), and their classmates in Group A ($p < .05$, Cohen’s $d = 1.14$).

The same tests were performed for the “Ways of Contributing” subcategories, with significant differences depicted in Figure 38. Significant differences were found for “asking factual questions” $F(3, 61) = 3.82$, $p < .05$, with Group B from 2012 outperforming the 2010 class on this measure ($p < .05$, Cohen's $d = 0.77$). Similarly, a significant difference was found for "proposing an explanation" $F(3, 61) = 2.47$, $p < .05$, with Group B contributing more to this category than the 2010 class ($p < .05$, Cohen's $d = 0.77$). Differences were also found on "introducing a new fact from a source" $F(61, 3) = 6.89$, $p < .001$, with results showing again that Group B contributed significantly more in this subcategory than the 2010 class ($p < .01$, Cohen's $d = 1.18$), the 2011 class ($p < .05$, Cohen's $d = 0.96$), as well as Group A ($p < .01$, Cohen's $d = 1.18$).

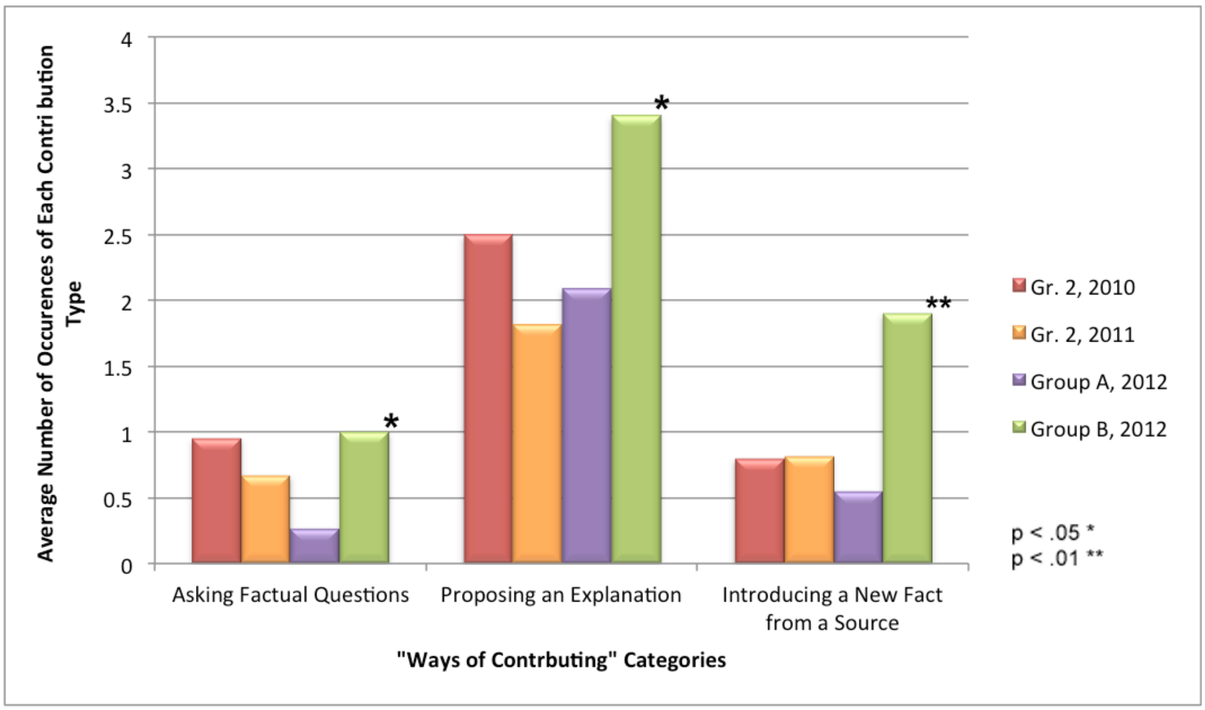


Figure 38. Means (*n*) for contribution subtypes in online discourses showing significant differences across four groups

In regard to secondary contribution measures, analysis revealed significant differences for the following: total notes $F(3, 61) = 7.97$, $p < .001$; total contributions $F(61, 3) = 9.50$, $p < .0001$; contributor diversity for "Ways of Contributing" subcategories $F(3, 61) = 3.42$, $p < .05$ (see Figure 39). Post-hoc tests show that Group B wrote significantly more notes than the 2010 ($p < .01$, Cohen's $d = 3.37$) and 2011 classes ($p < .01$, Cohen's $d = 3.37$), as well as Group A (*p*

< .01, Cohen's *d* = 3.37). Accordingly, Group B also made more total contributions than these three other groups ($p < .01$, Cohen's $d = 3.70$) respectively. Group B also contributed more diversely than the 2011 class on subcategories ($p < .05$, Cohen's $d = 1.47$).

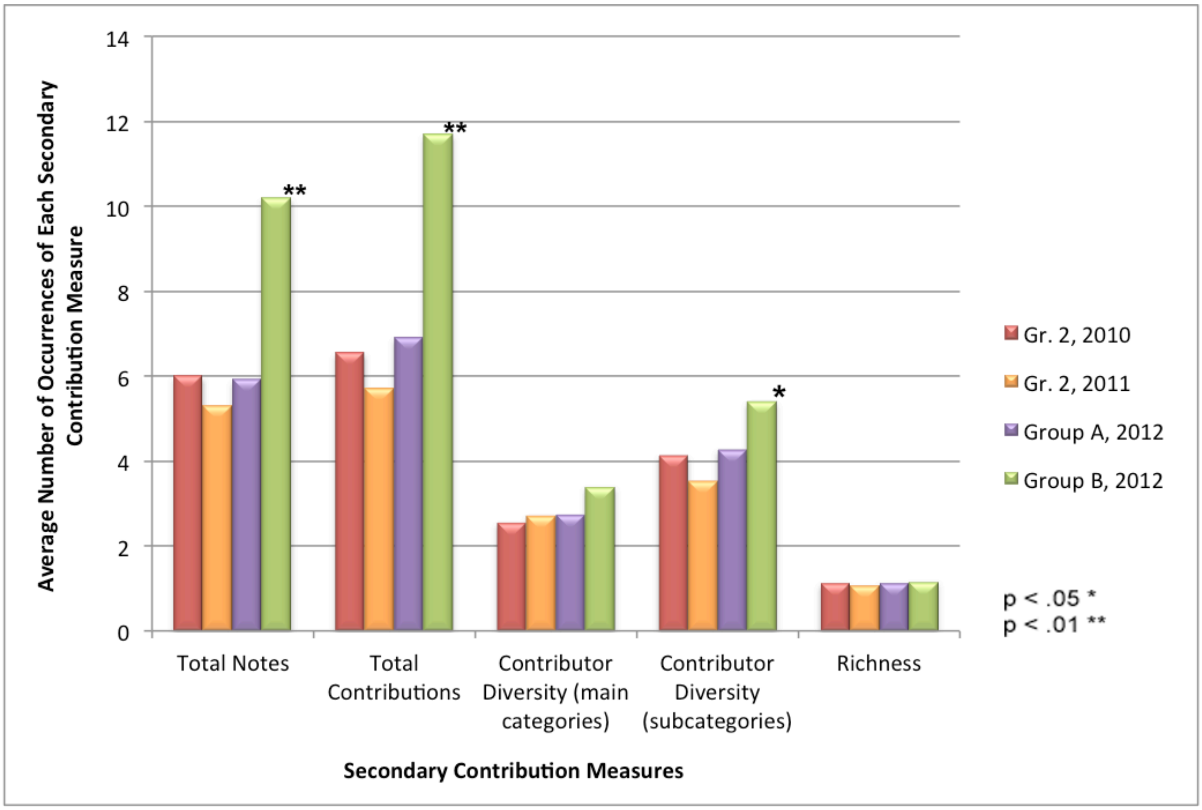


Figure 39. Means (*n*) for secondary contribution measures across four Grade 2 groups.

These three Grade 2 classes were also tested for any significant differences on knowledge advancement measures, and found that they existed for both "scientificness" $F(3, 60) = 24.87$, $p < .0001$, and "epistemic complexity" $F(3, 60) = 6.34$, $p < .001$ (see Figure 40). More particularly, post-hoc tests show that Group A achieved significantly higher scores on this measure than the 2010 class ($p < .01$, Cohen's $d = 0.74$), the 2011 class ($p < .01$, Cohen's $d = 0.74$). Group B also outperformed the 2010 class ($p < .01$, Cohen's $d = 0.74$), and 2011 class ($p < .01$, Cohen's $d = 0.74$). A difference was also found for "epistemic complexity," with the 2010 class achieving a higher score than the 2011 class ($p < .01$, Cohen's $d = 0.70$).

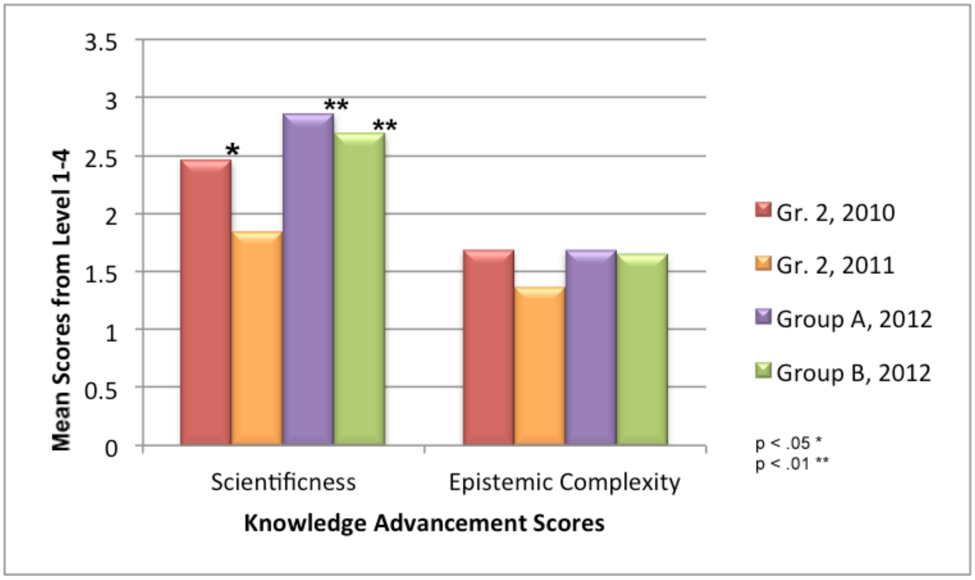


Figure 40. Means (*n*) for knowledge advancement scores for Grade 2, 2011 and Grade 2, 2012.

Comparisons between the experimental Grade 2, 2012 class and two preceding Grade 2 classes shows that treatments consisting of engaging students in repeated metadiscourse sessions and exposing them to contribution-oriented formative feedback helps students to significantly increase their performance on a variety of contribution types that are vital to explanation-seeking discourse and to scientific inquiry as well, such as asking thought-provoking questions that can initiate and propel an inquiry, contributing original ideas, reporting useful and relevant information from authoritative sources, as well as offer empirical observations from experiments and other hands-on forms of research. Contribution-oriented formative feedback such as that produced by the Metadiscourse Tool appears to be especially helpful for encouraging young students to introduce new and useful facts to the shared discourse, write a considerable amount of notes and accordingly make a high number of contributions.

Helping students at this grade level to expand their contribution repertories to include working constructively with authoritative knowledge to a greater extent was the intent of this study, and so increased performance in this area was anticipated. However, what was unexpected was the increase in writing and contributions made by the students subject to both metadiscourse and the feedback. It seems that there is a synergistic effect between the visual feedback provided by the Metadiscourse Tool and the metadiscourse discussions, compelling motivation and participation in writing and contributing ideas to the database.

5.6.2 How did the experimental Grade 2 class fare on contribution and knowledge advancement measures in comparison with other grades?

I was also interested in exploring how the Grade 2, 2012 class's performance on contribution measures and knowledge advancement measures held up against the remaining four classes from the 2010 study. So, one-way ANOVA comparison tests on these five groups was conducted to explore the performance of Grade 2, 2012 in comparison to the Grades 1, 3, 4 and 5/6 students from the 2010 school year (see Figure 41). Recall that the Grade 2, 2010 class was

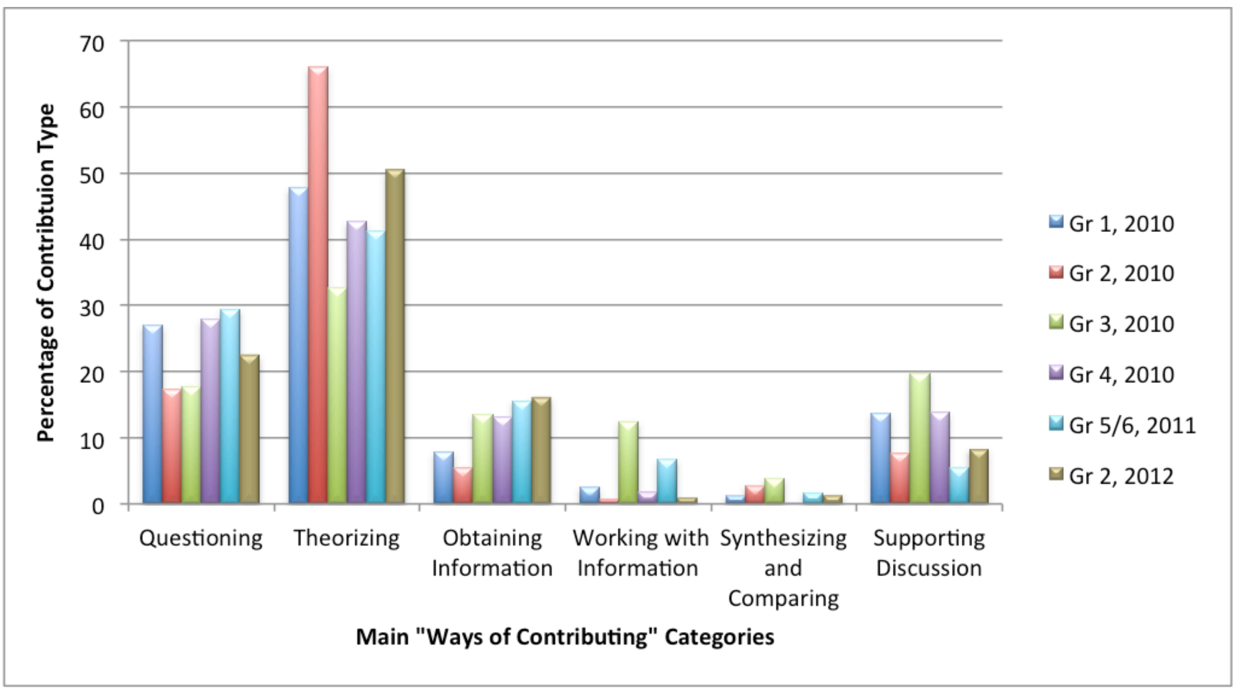


Figure 41. Percentage of notes containing each main "Ways of Contributing" type in the online discourses of Grades 1-6, plus the experimental Grade 2, 2012 class.

outperformed on the following measures by the corresponding grades: The Grades 1, 4, and 5/6 classes outdid the Grade 2, 2010 class on "Asking Thought-Provoking Questions," namely "explanatory questions" (Grade 1) and "factual questions" (Grade 5/6); the Grade 1 class did better on "Theorizing," particularly "seeking an alternative explanation" than the Grade 2, 2010 class; the Grade 5/6 students outperformed the Grade 2, 2010 students on "Obtaining Information," namely "introducing a new fact from a source"; last, the Grade 1 class did better on "Supporting Discussion" than the Grade 2 class, particularly "giving an opinion."

Findings from one-way ANOVA comparisons between the Grades 1, 3, 4, and 5/6 classes to the experimental Grade 2, 2012 class, followed by post-hoc tests (Tukey HSD) reveal a number of interesting results. First, the Grade 1 students still outperformed the experimental Grade 2 students on all the same measures, namely, "Asking Thought-Provoking Questions" $F(4,100) = 7.26$, $p < .0001$, ($p = .05$, Cohen's $d = 2.69$) specifically "explanatory questions" $F(4,100) = 6.56$, $p <. 0001$, ($p = .01$, Cohen's $d = 2.54$), as well as "Theorizing," $F(4,100) = 4.71$, $p < .01$, ($p < .05$, Cohen's $d = 4.62$), specifically "supporting an explanation" " $F(4,100) = 3.34$, $p <. 05$, ($p < .05$, Cohen's $d = 1.68$) as well as "seeking an alternative explanation" $F(4,101) = 3.39$, p < .01 ($p < .05$, Cohen's $d = 1.03$), and finally "giving an opinion" $F(4,100) = 4.38$, $p < .01$, ($p < .05$, Cohen's $d = 1.40$). Whereas the experimental Grade 2 class did not show improvements in comparison with the Grade 1, 2010 class, they did raise their level of performance as contrasted to the Grade 4 and 5/6 students. For instance, the students from the Grade 2, 2012 class asked just as many questions as the Grade 4 and 5/6 classes, unlike their peers from the 2010 class. Also, the experimental Grade 2 students did not differ significantly in their performance on "Obtaining Information" nor "introducing a new fact from a source" from the Grade 5/6 students, as their counterparts had in 2010 (see Figure 42).

This trend is echoed when looking at results from analysis of the secondary contribution measures (see Figure 43). For instance, comparing the 2012 Grade 2 class with the four other classes from 2010, a significant difference was found for total notes $F(4, 100) = 6.33$, $p < .0001$, and total contributions $F(4, 100) = 4.35$, $p < .01$. Post-hoc tests (Tukey HSD) revealed that the Grade 1 class still outperformed the experimental Grade 2 class ($p < .01$, Cohen's $d = 8.70$,) on

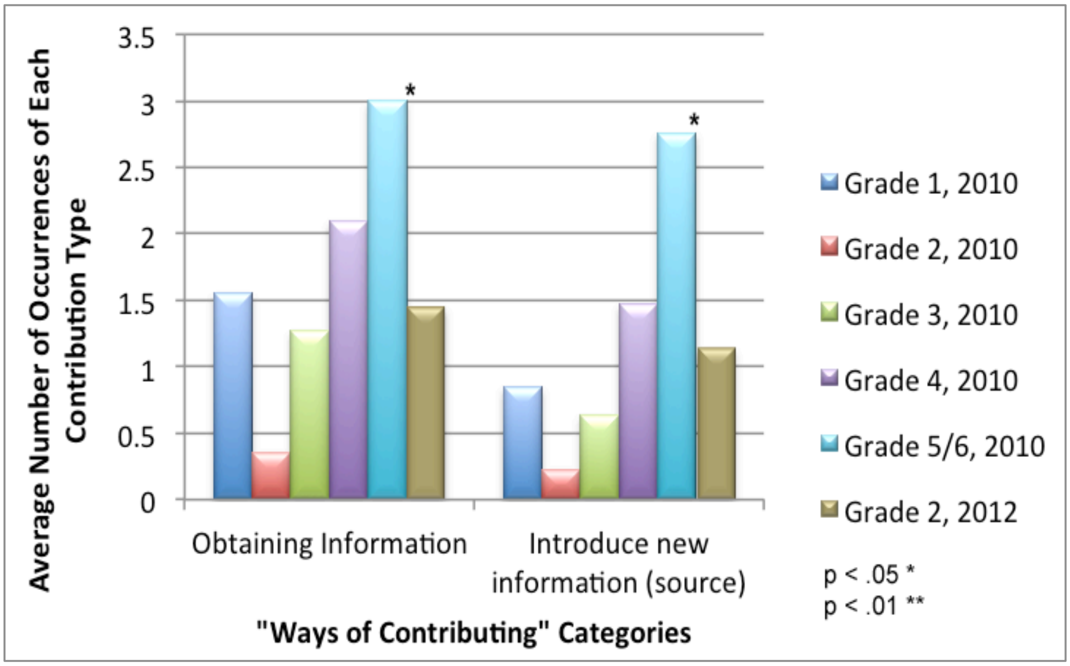


Figure 42. Percentage of notes containing select contribution types in the online discourses of Grades 1-6, plus the experimental Grade 2, 2012 class.

total notes written as well as total contributions ($p < .05$, Cohen's $d = 9.32$). The Grade 5 students also outperformed these Grade 2 students on total contributions ($p < .05$, Cohen's $d = 9.32$). Whereas the Grade 1 class outdid the Grade 2, 2010 class on the measure of contributor diversity in regard to the main categories, and the Grades 4 and 5/6 classes did so with respect to the subcategories, no significant difference was found for contributor diversity on either level between these grades and the Grade 2, 2012 class.

Last, identical comparison tests on knowledge advancement measures across the five groups, show significant differences with respect to "scientificness" $F(4, 96) = 10.69$, $p < .0001$ (see Figure 44). More specifically, whereas the Grade 2, 2010 class was outperformed by the Grade 5/6 students on this measure, the experimental Grade 2, 2012 class performed better than the Grade 1 class at "scientificness" ($p < .01$, Cohen's $d = 0.65$), and the Grade 3 classes (p

< .01, Cohen's *d* = 0.65), with no significant differences found between these students and the Grades 5/6 students.

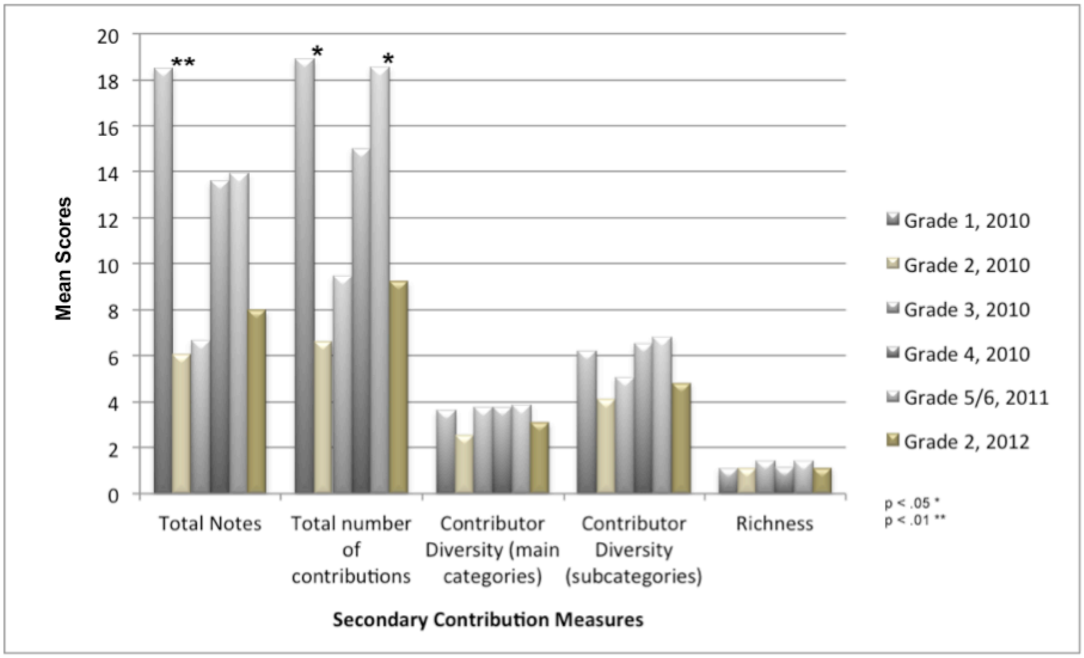


Figure 43. Means (*n*) for secondary contribution measures across Grades 1-6, plus the experimental Grade 2, 2102 class.

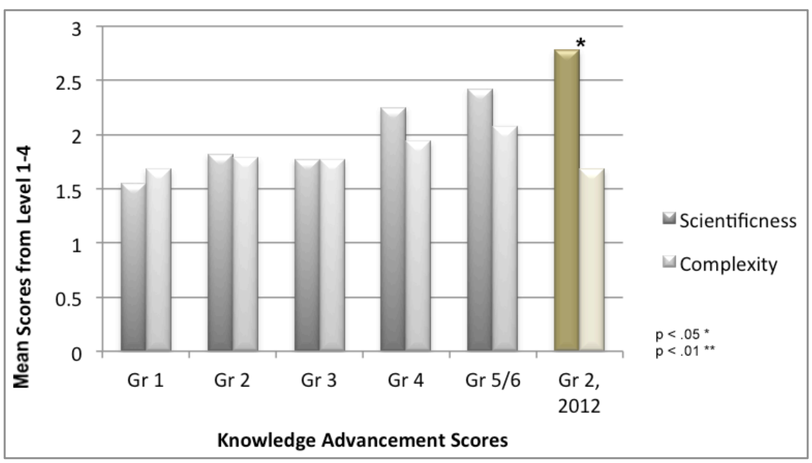


Figure 44. Means (*n*) for knowledge advancement scores across Grades 1-6, plus the experimental Grade 2, 2012 class.

These findings indicate that the treatments implemented in the Grade 2, 2012 class seemed to help students to both outdo peers at the same grade level, as findings reported above suggest, but also raise increase their achievement to parallel performance scores at higher grade levels on particular contribution types—in this case, "Asking Thought-Provoking Questions" and "Obtaining Information"—as well as on contribution diversity in general. Metadiscourse and contribution-oriented feedback also had a positive effect on the "scientificness" of students' theories. These results indicate that targeting specific contribution types by having explicit discussions with students about their importance and by facilitating such discussions with contribution-oriented formative feedback visuals can enhance students' performance in these as well as other non-targeted contribution types.

5.7 Lessons Learned from Design Cycle 1

A number of insights were gained during research in Design Cycle 1 that reinforced certain aspects of the study and informed changes to be implemented in Design Cycle 2. For example, while a few elements of the study, such as metadiscourse discussions, had beneficial outcomes, other components, such as the Contribution Clouds, proved less valuable. In the section that follows, I provide commentary on the strengths and weaknesses of various aspects of the design, and briefly introduce changes planned for Design Cycle 2.

5.7.1 Lesson 1: Productive design components

With respect to the use of formative feedback, one of the strongest outcomes of the study were the positive effects of metadiscourse to the work of the Grade 2 students. The teacher and I were repeatedly impressed by the quality of the dialogue students engaged in during these sessions, and were pleased that the knowledge advances that were being made in offline discourse also crossed over to the online work the students conducted, as evidenced in the quantitative analysis described above. Also, the teacher reported to me that she had a discussion with the class at the end of the year, just under a month after the last Knowledge Building unit had concluded, and asked them about what activities and events over the past school year they thought were the most useful in helping them to learn. Students that had been in Group B told her that looking at feedback generated by the Metadiscourse Tool was one of the most beneficial things they felt that they did with their "KB talk" time. The results of data analysis support these claims, as exposure to this feedback compelled students to write more notes and to make more contributions to the online discourse.

Moreover, targeting the contribution type "Obtaining Information" was a success, and resulted in extension of contribution repertoire in this area. However, given that students in Group A particularly appeared to engage less in three out of four of the "Theorizing" subcategories than they did in Grade 1, for the next design cycle it was important that children did not feel dissuaded from contributing from other important types as an unintentional byproduct of emphasizing engagement in other typically low-frequency contribution modes. Thus, the teacher decided that all students in the next iteration would view the Metadiscourse Tool, as this appeared to have beneficial effects for helping students to maintain more diverse contribution repertoire over time.

In sum, reproducing the results achieved in this iteration in Design Cycle 2, namely the growth in student contributor repertoire and advancement of community knowledge, will be important for providing empirical evidence of feedback that can successfully raise the level of students' explanation-seeking discourse. Thus, both metadiscourse sessions and the Metadiscourse Tool remained central to treatments conducted in the next design cycle.

Finally, the classroom teacher found that the Concept Cloud visualizations that displayed key words were beneficial to generating conversation and opening up new avenues of inquiry, providing a means to introduce new and challenging concepts to the students in an authentic context. She also appreciated having records of the ways the key terms that students were using changed over time, as well as possessing evidence of how students' discourse mapped onto expert vocabulary as the inquiry progressed. For instance, Figure 45 depicts how students' discourse about owl pellets, which they dissected in class, was initially dominated by talk around dirt. During metadiscourse sessions, students could compare the "Our Words" word cloud to the "Expert Words" word cloud, and could see that "dirt" was not present in the expert discourse. While the inquiry progressed, talk around dirt subsided to discussion featuring other relevant terms, such as "digest," "bones" and "gizzard" (see Figure 45). While it cannot be claimed that the Word Clouds were the direct cause of this shift, displaying the differences between the vocabulary makeup of their dialogue and that of expert discourse helped students become aware of important differences. In general, the teacher found that using Word Clouds as facilitation for group reflection helped students to not only reflect on the ideas and terms that were present in their discourse but also on terms that were absent or receiving less attention. It is likely that the value of the Word Clouds is derived not in and of themselves as visualizations but mainly from their use as an object of collaborative, reflective discourse with students at this young age.

Figure 45. Concept clouds showing terms characterizing students' discourse near the beginning of the inquiry (far left), near the end of the inquiry (centre) and a Concept cloud showing "expert" terms related to owl digestion.

Because of the success of the Word Clouds in this iteration, the use of KBDeX to generate another variation of the Word Clouds in the next iteration of the study was deemed promising. For instance, KBDeX can produce Word Cloud visualizations that not only highlight the key words in a dialogue but can make explicit the connections and relationships between these words. Foregrounding key terms and concepts as well as displaying the semantic relationships between them represents a refinement to the Word Clouds that could help students reflect on the state of their discourse in meaningful ways.

5.7.2 Lesson 2: Design components that can be improved

In regard to elements of the study that were not so successful, the "Our Contribution" version of the Word Clouds stood out as being the least useful type of feedback visualization. It was determined that these types of Word Clouds would not be used again in Design Cycle 2 and that another approach would be adopted to try to help students revisit and evaluate overlooked aspects of their discourse. In regard to the newly introduced scaffolds, while the students expressed an understanding and a desire to use the scaffold "This information is important because," its actual use in students' notes remained very low, (present in only 2 out of 175 notes). Thus, in this case, this scaffold was not successful in helping students to expand contribution types that mapped onto "Working with Information", as was the intention. Because students showed a capacity for drawing broader connections between ideas during metadiscourse sessions, it was decided that a new scaffold designed to help students synthesize and make connections between ideas during reflective group discussion would be tested, and that explicit focus on "Working with Information" would not continue. Last, while the Grade 2, 2012 class achieved significant advances in understanding regarding the life cycles of birds and fish, the teacher hoped that discussion would move to engage more deeply the "big ideas" related to this particular curriculum stream such as evolution and adaptation. Thus, the next design cycle will also include more focused consideration on ways to support discourse that encompasses these themes.

5.8 Chapter Summary

In this chapter, I reported the results of a study conducted over the course of eight months geared towards expanding the contribution repertoire of Grade 2 students doing Knowledge Building work in science. First, the principles informing the study design were laid out. Next, the plan of analysis was explained, including a detailed outline of the procedure of treatments that were integrated within the class. A summary of results followed, detailing both quantitative and qualitative outcomes of the study. More specifically, quantitative measures tested the performance of two experimental groups in the 2012 class—Group A and Group B—each of which received a variation of treatments throughout the school year. Findings showed that Group B performed significantly better on secondary contribution measures, including total notes, total contributions, and contributor diversity. Thus, the use of the Metadiscourse Tool did not result in a significant increase of one type of contribution move over another, but it did help students make more types of contributions more often. Both groups were then compared to the previous year's Grade 2 (2011) class on all measures, including both contribution and knowledge advancement measures. Results showed that the experimental class (2012) performed better than their peers a year prior on "Obtaining Information," "proposing an explanation," as well as "reporting experimental results." These findings suggest that reflective group discussion can help students contribute significantly more original ideas, and that the explicit talk about contribution types such as "Obtaining Information," facilitated by the Metadiscourse Tool, can help students expand their contribution repertoire in targeted areas. Moreover, both groups in the 2012 class had significantly higher knowledge advancement scores than the benchmark class (2011). These findings imply that engaging students in consistent metadiscourse sessions and exposing them to visualizations produced by the Metadiscourse Tool can have a positive effect on their Knowledge Building work.

Data was also triangulated with a Grade 2 class from two years prior (2010), to determine whether any patterns or consistencies with the results could be detected. One-way ANOVA comparisons were conducted on contribution and knowledge advancement measures between the four groups – the 2010 class, the 2011 class, and Group A and Group B from the 2012 class. Findings showed that the experimental treatments helped students to significantly increase their performance on a variety of contribution types that are critical to explanation-seeking discourse and to scientific inquiry, such as asking thought-provoking questions that can initiate a sustained and deep inquiry, contributing original ideas, reporting useful facts and information from secondary sources, as well as offer empirical observations from experiments and other hands-on forms of research. The Metadiscourse Tool seems to be especially useful for helping young students introduce new and relevant facts to the shared dialogue, to write a greater amount of notes, and accordingly to make a high number of contributions to the discourse. This latter finding was unanticipated, and suggests that there is a synergistic effect between the visual feedback presented by the Metadiscourse Tool and the metadiscourse discussions which helps compel motivation and active participation in the online discourse.

Following quantitative results, commentary on the offline discourse was included in order to give a richer description of the nature and quality of student dialogue. Discussion focused on the ways students were advancing knowledge related to the major streams of inquiry (e.g. "how birds fly"), the ways in which students interacted with the feedback visuals, the ways students' contributed to targeted contribution types, and the sorts of verbal contributions they made during whole class metadiscourse sessions. Finally, the strengths and weaknesses of the study design were evaluated. The chapter concluded with the identification of elements of the study that will continue on, as well as those that will be changed or abandoned in the next design cycle.

CHAPTER 6: SECONDARY ANALYSIS: THE EFFECT OF FORMATIVE FEEDBACK ON VOCABULARY USE AND DISTRIBUTION OF VOCABULARY KNOWLEDGE

6.1 Chapter Overview

This chapter reports secondary analysis conducted on the data examined in the previous study and explores how formative feedback supports designed to boost students' ways of contributing to explanation-seeking discourse might also have an impact on students' literacy skills, particularly growth in productive written vocabulary. The study also examines the extent to which new and important terms are distributed throughout shared discourse as students work to collaboratively build knowledge in science.[3] The chapter is comprised of the following: i) a brief discussion about literacy learning from a socio-cognitive perspective; ii) an overview of the method and plan of analysis for assessing productive vocabulary use and knowledge, as evidenced in students' writing on Knowledge Forum; iii) a summary of findings and discussion of results; iv) concluding remarks.

6.2 Knowledge Building for developing literacy

Literacy is a fundamental aspect of education, and is bound up with the ability to work creatively with ideas. In a broad sense, basic literacy entails an ability to read and write with understanding, use information productively from a range of sources, as well as use language effectively to build and communicate ideas. Literacy enables knowledge creation, and enhances the ways students' contribute to explanation-seeking dialogue. For instance, in a progressing

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[3] The research reported below is elaborated from a study that will be published in the 2013 CSCL conference proceedings (see Appendix D). Here, I include samples of student writing as a component of qualitative analyses not incorporated in the aforementioned paper.

discourse, students are continually introducing useful information from authoritative sources, articulating their own theories, synthesizing available information, and so on. In turn, the effort to collaborative build increasingly coherent explanations to authentic problems of understanding can motivate students to hone and sharpen basic skills and as such help develop higher-level competencies in reading, writing and communicating. As described by a Grade 1 Knowledge Building teacher "my grade will come to me with books that really are pretty hard for them to read, not way above their reading level, but enough, but they are so interested…they'll show me the page, and they are working just so hard to read it because they really want to know what the book says" ("Teacher's perspective on Knowledge Building," 2012). Thus, the development of literacy competencies occurs as part of the dynamic process of improving ideas even at the early primary level.

In terms of particular skills, the development of literacy also includes the use and growth of vocabulary. Research has shown that greater knowledge and use of vocabulary is a reliable predictor of reading and writing comprehension (Stahl, 1991) as well as verbal and listening skills (Steahr, 2009). Studies also show that learning a new word is not a singular event, but happens over time, with increased and varied usage indicating deeper understanding (Nation, 2001). From a socio-cognitive perspective, developing literacy requires integrating language learning within authentic pedagogical practices that embed language use within inquiry and problem solving processes (Applebee, 1981; Bereiter & Scardamalia, 1987). Integrated contexts of literacy that promote productive vocabulary use and growth thus engage students in meaningful activities related to new or difficult words, expose them to multiple and varied encounters with these words, and give them opportunities to utilize such words in speaking, reading, writing and listening (Stahl, 1991). Authentic literacy practices engage students in these activities not only in the interest of language acquisition, but in the service of authentic inquiry and problem solving; such instructional environments have been shown to be more effective for language learning than direct instruction with respect to depth of word knowledge, writing quality and expansion of vocabulary (Stahl, 1991; Yonek, 2008).

With its focus on immersing students in shared discourse for solving problems of understanding, Knowledge Building practices present conditions highly conducive for effective vocabulary learning and provides a rich context to engage students' in authentic literacy practices that involve individual and co-operative reading, writing, idea development, active research, and sustained collaborative dialogue (see Sun, Zhang, & Scardamalia, 2010). Students are offered rich opportunities to introduce new vocabulary within inquiry-based work, negotiate and infer word meanings, and use available sources to help them deepen their knowledge of new words.

In this study, the discourses of two Grade 2 classes are explored. Both classes engaged in two Knowledge Building units in science, with a focus on the life cycles of birds and salmon. The focus is on the development of productive written vocabulary as evidenced in students' writing on Knowledge Forum. Productive use of vocabulary entails that students display a diverse range of words in their writing in a way that conveys understanding. Richness in student vocabulary includes use of both domain-specific and epistemological terms or "academic words" (Coxhead, 2000). Productive use of domain-specific vocabulary is indicative of grasping core content and language, with frequent use of domain specific words indicative of integration into a discursive community (Chernobilsky, DaCosta,& Hmelo-Silver, 2004). Similarly, "academic words" (e.g. *source, theory, hypothesis*) refers to terms that occur at a reasonably high frequency rate in academic discourse; these words cross domains and generally correspond with higher level knowledge work. Academic words typically appear in students' discourse at a relatively late age, beginning in adolescence and increasing with post-secondary education (Laufer, 1994).

So, is it plausible to expect children of primary school age to use sophisticated vocabulary in their written work? According to research on reading progression (Chall, 1996), the spectrum of learning across which both reading comprehension and vocabulary usage take place is characterized by important developmental changes. According to this framework, in primary level grades students are still "learning to read"—gaining foundational phonetic knowledge—rather than "reading to learn," which involves higher level cognitive processes and does not typically begin to take place until approximately Grades 4-6 (Chall, 1996). However, this progression is not a rigid series of sequential stages, but an overlapping continuum that is based on approximate grade and age levels; furthermore, the developmental steps are dependent to a considerable extent upon the learning environment itself (Chall, 1996). Research shows that exposing students to specialized fields of discourse on a repeated basis in authentic language-learning settings can help foster the productive use of sophisticated words (Corson, 1997). Immersing students in settings that include speaking and listening along with reading and writing is particularly beneficial for lower-level readers (Beimiller, 2001). Similarly, research shows that even with a single exposure, a word encountered in a richer context is more likely to be learned than is one in a less rich context (Herman, Anderson, Pearson, & Nagy, 1987). Combining reading and writing activities with explicit vocabulary learning has been shown to be a highly effective strategy for language learning (Stahl & Fairbanks, 1986). In addition, the use of formative assessments to enhance learning is widely recognized (Black & William, 1998; Marzano, 2006; Stiggins, 2004). Formative assessments integrated within computer-supported learning environments have also been shown to be beneficial for learning (Tseng & Tsai 2007). Moreover, studies show that vocabulary-based feedback such as word or tag clouds provide useful overviews of knowledge that highlight key concepts (Hearst & Rosner, 2008) and aid in semantic exploration and comprehension of data by users (Bateman, Gutwin, & Nacenta, 2008).

These findings support the notion that even students as young as the second grade can learn and use complex vocabulary productively if conditions and resources are conducive to such learning.

A Knowledge Building approach has been shown to provide such conditions. For example, research has shown gains in vocabulary and comprehension as by-products of collaborative Knowledge Building work with no direct focus on vocabulary learning and text comprehension (Scardamalia et al., 1992). Furthermore, children as young as junior kindergarten have shown gains in literacy using this approach (Pelletier, Reeve, & Halewood, 2006). Looking at vocabulary growth in Knowledge Building students across Grades 3 and 4, Sun, Zhang, & Scardamalia (2010) traced an increase of use of academic words of almost four percent on average, and found positive correlations between use of sophisticated vocabulary with depth of understanding. Where benefits in Knowledge Building work for literacy are reported, this study will be the first to focus on the role of formative feedback targeted to enhance students' vocabulary knowledge.

Moreover, examining students' capacity for building new knowledge calls for collaborative, emergent knowledge advancement in addition to individual assessments. Because the emphasis of Knowledge Building is on collective rather than individual achievement, examining the way Knowledge Building students work together is important for understanding how members share and create collective knowledge. To this end, a social network approach was applied in this study to explore group-level dynamics and to highlight significant interactions with respect to vocabulary use and growth. As defined by Haythornthwaite and de Laat (2012) social networks can be understood as "configurations of connectivity that exist when people interact with each other by communicating, sharing resources, and working, learning or playing together, supported through face-to-face interactions as well as through the use of educational, and information and communication technology" (p. 352). From a social network perspective, a network is a "living entit[y]" (Haythornthwaite, 2008, p. 154), an emergent structure that is comprised of "a common definition of words, actions, practices, and technologies that no individual can enact" (p.153). A social network approach to exploring learning environments places emphasis on interactions and on community structures that arise from these interactions (Haythornthwaite & de Laat, 2012, p. 353), and can illuminate underlying patterns and structures that reveal how knowledge moves within a network and to what extent group members are connected (Haythornthwaite, 1996; Wasserman & Faust, 1994). Given that the interactions between members in a network are "the building blocks that sustain and define groups" (Haythornthwaite, 2001 p. 213), examining the group network structure of a community of Knowledge Building students is important for identifying important dynamics that characterize the community, and its shared discourse—the extent to which collective knowledge is reaching every student, whether certain students are socially or discursively isolated from the larger group, the degree to which ideas are being contributed and taken up amongst members, and so on. Thus, in order to broaden the study to evaluate both individual achievement as well as group-level dynamics, this study will explore the underlying network structure of two Knowledge Building discourses to illustrate how discursive interactions help shape the respective student communities and to determine the extent to which vocabulary use was distributed throughout each group.

6. 3 Co-Designing the vocabulary study

Because this study represents a secondary analysis of existing data, the methodological design rests upon the same foundational principles as the study reported in Chapter 5. However, because this study shifts focus from assessing expansion of contribution repertoire to achievements in literacy, in the section below I elaborate briefly on how the principle of *constructive use of authoritative sources* supports literacy learning in particular. I also briefly discuss an additional principle, that of *symmetrical knowledge advancement*, and how it relates to the objectives of this study.

6.3.1 Creating a principle-based design

(a) *Constructive use of authoritative sources:* This principle requires that students engage with "expert" texts and information in a way that is both critical and conducive to improving their own ideas. This practice involves encountering unknown terms and concepts, and applying them to students' own ideas. In the experimental class (Grade 2, 2012), students were encouraged to explore unknown words and find relevant sources to help them understand new or challenging vocabulary. After metadiscourse discussions students moved onto writing in Knowledge Forum, often forming small groups or working in pairs to find resources to help them learn more about the important terms just discussed. Students engaged in co-operative reading, writing and discussion about these words, and worked to acquire definitions of new words as well as integrate them into group discourse.

(b) *Symmetrical knowledge advancement*: This principle implies that knowledge and expertise flow within and between community members working on shared problems in the interest of idea improvement. The distribution of knowledge across a community is important in the context of vocabulary learning, especially in the early years. Research shows that children who acquire literacy skills in the early years of schooling are more likely to experience success at higher levels of education, with the reverse also holding true (Stanovich, 2000). Simply put, children who know more words can learn more words (Stahl, 1991). The collaborative metadiscourse discussions, coupled with visualizations designed to give students a meta-level perspective on critical aspects of their own discourse, were aimed at engaging all students in various literacy practices including reading, speaking, listening as well as writing, so that productive vocabulary use was distributed throughout the group discourse.

It was hypothesized that students in the experimental class would demonstrate a greater degree of productive written vocabulary than the benchmark class from the previous year. It was also predicted that the more expansive the vocabulary, the greater the knowledge advancement of the community. Moreover, it was predicted that vocabulary use in the experimental class would be used and distributed across time and groups to a greater extent than in the benchmark class. Last, it was hypothesized that Group B from the experimental class would contribute more diversely than Group A or the Grade 2, 2011 class, and correspondingly exhibit greater knowledge advancement.

6.4 Method and Analyses

This section reports the method and modes of analyses used in this research.

6.4.1 Participants and classroom context

Participants for this study included 42 Grade 2 students from two consecutive classes—21 students (11 boys, 10 girls) from the 2010-11 Grade 2 class, and 21 students (10 boys, 11 girls) from the 2011-12 school year. These are the same classes that participated in the study described in Chapter 5, so the classroom context, including units and duration of studies, is the same as those described in the previous chapter (see Section 5.3.1, Chapter 5). To reiterate, the 2010-2011 class did not participate in any design experiments, and thus they provide the benchmark data for this study. The 2011-2012 class is the experimental class. Within this class, two student groups (Group A and Group B) each received a different design intervention, as elaborated below.

6.4.2 Procedure

The implementation of treatments is the same for this secondary analysis as that described in the Chapter 5 (see Section 5.3.2).

6.4.3 Dataset

The dataset for this analysis is the same as that described in the Chapter 5 (see Section 5.3.4).

6.4.4 Plan of analysis

The application of behavioural, lexical, and group-level dynamics, are summarized as follows:

(a) *Behavioural Measures:* The Knowledge Forum Analytic Toolkit (Burtis, 1998) was used to calculate the number of notes authored per student and the percentage of notes read per student.

(b) *Lexical Measures:* Lexical profiles were calculated for each student using the Knowledge Forum Analytic Toolkit. Researchers manually corrected spelling errors so that the automated tools picked up all words. Three attributes were used to create students' lexical profiles, and include the following: i) academic words; ii) 1st, 1000 words; iii) domain-specific words. The Academic Word List (AWL) is composed of 570 written families external to the 2000 most frequently used English words but common in academic discourse. The 1st, 1000 words refers to a lexicon consisting of the most frequently used words in English, plus their grammatical variations. Greater use of high frequency words is indicative of a more limited vocabulary (Nation, 2001). With respect to domain-specific words, two inquiries were conducted to generate a single word list. First, researchers consulted the Ontario Curriculum Standards document for Science and Technology and identified key words corresponding to the "Understanding Life

Systems" stream, which runs from Grades 1-8, becoming "Biology" in Grades 9-10. The words selected totaled 342 individual terms that ranged across Grades 1-10 and focused on key aspects of this stream, such as "Growth and Changes in Animals," "Biodiversity," "Interactions in the Environment," and "Sustainable Ecosystems." Words selected from the curriculum document were divided into two levels according to the grade in which they appeared in the curriculum document. 84 words were identified at or below the Grade 2 level, and 258 words above the Grade 2 level. In addition to this, external sources available in the classroom were used to identify terms critical to particular streams of inquiry as they emerged during the course of Knowledge Building work. These words appeared on the word cloud visualizations to help students expand their vocabulary repertoire. For analysis, a total of 64 "expert" words were combined with the 342 curriculum words to create a single comprehensive list. This cumulative list, which totaled 406 words, plus their grammatical variations, was used to measure domain-specific vocabulary (see Appendix G).

(c) *Depth of Understanding:* Measures derived from the primary study described in Chapter 4 were applied to this analysis.

(d) *Group Discourse Network Structure:* KBDeX is a tool developed for Knowledge Forum that is designed specifically to map the network structure of collective discourse based on co-occurrence of words in discourse units (or Knowledge Forum notes). Important group-level dynamics were derived from source text (students' notes), with network structure of community discourse shown in three ways: first, the social network of the student community was shown, based on common vocabulary across all student notes; second, connections between notes were used to show ties and relations between unique discourse units (e.g. notes); third, connections between individual words depict semantic associations in the discourse. Both word networks and note networks are created by a *notes* × *words* bipartite network, with student networks based on a *words x students* graph. The visualizations of all of these networks are depicted as a one-mode projection of a bipartite network. For details see (see Matsuzawa, et al., 2011).

For this study, each class's discursive network was analyzed on the social and individual word levels according to Degree Centrality (DC), Betweenness Centrality (BC) and Closeness Centrality (CC), which represent standard points of analysis in complex network science (e.g., Newman, 2010). Degree centrality measures the "popularity" or number of connections one node has with other nodes in the network. In this case, each network node represents a student or a word, with connections between students created through the use of the same word, and connections between words created when one word appears in the same written note as another word. So, the more discursive connections a student has with other students, or a word with other words, the more "popular" or centralized that student or word is in the network. Betweenness centrality provides a valuable measure at both a local and global level, and indicates the degree of connectivity of a node, as well as the "load" placed on the node by all other nodes. For this research, this measure reveals the extent to which students or words are connected within a community and the degree to which they bridge various social clusters or discursive cliques, respectively. Closeness centrality measures the proximity of one node to all other nodes, and is indicative of how quickly information can flow through a network. Applied to this case, this measure reveals how closely connected students are to each other via the discourse they are engaging in, or, in the case of words, the semantic context in which they are being used. The particular domain-specific and academic words used by the students in each class, generated from their lexical profiles, were used to comprise two separate word lists for group analysis in KBDeX. In this way, the discursive relationships between students and words characterizing the collective discourse could be mapped.

6.5 Results

The section below details the research results, including description of findings for both behavioural, lexical, and knowledge advancement measures. Network structure analysis also reports the extent to which vocabulary knowledge was distributed throughout the community.

6.5.1 Did the experimental class exhibit more productive vocabulary growth than the benchmark class?

Table 9 below outlines mean scores for each group on behavioural and lexical measures. As Figure 46 shows, Group B from the 2012 class scored highest on one of two behavioural measures, namely number of notes written, while, the 2011 class read the highest percentage of notes. Figure 47 illustrates that Group B from the 2012 class outperformed the other two groups on all lexical measures besides % of Notes Read, % of Academic Words, and % of 1st 1000 words. The 2011 class used the most words from the 1st 1000 word category, while all groups had virtually the same average use of Academic Words (averaging .55% of overall word use).

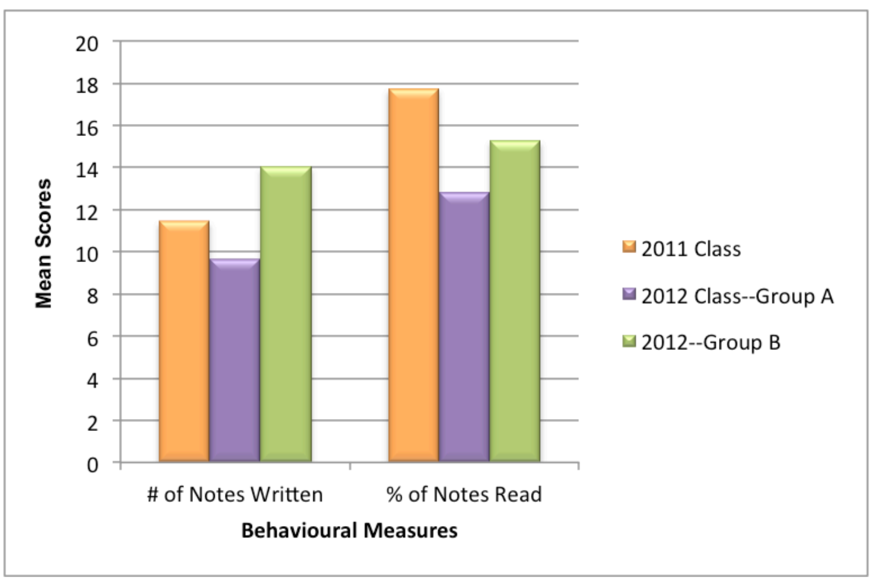

Figure 46. Means (*n*) across behavioral measures for the three student groups.

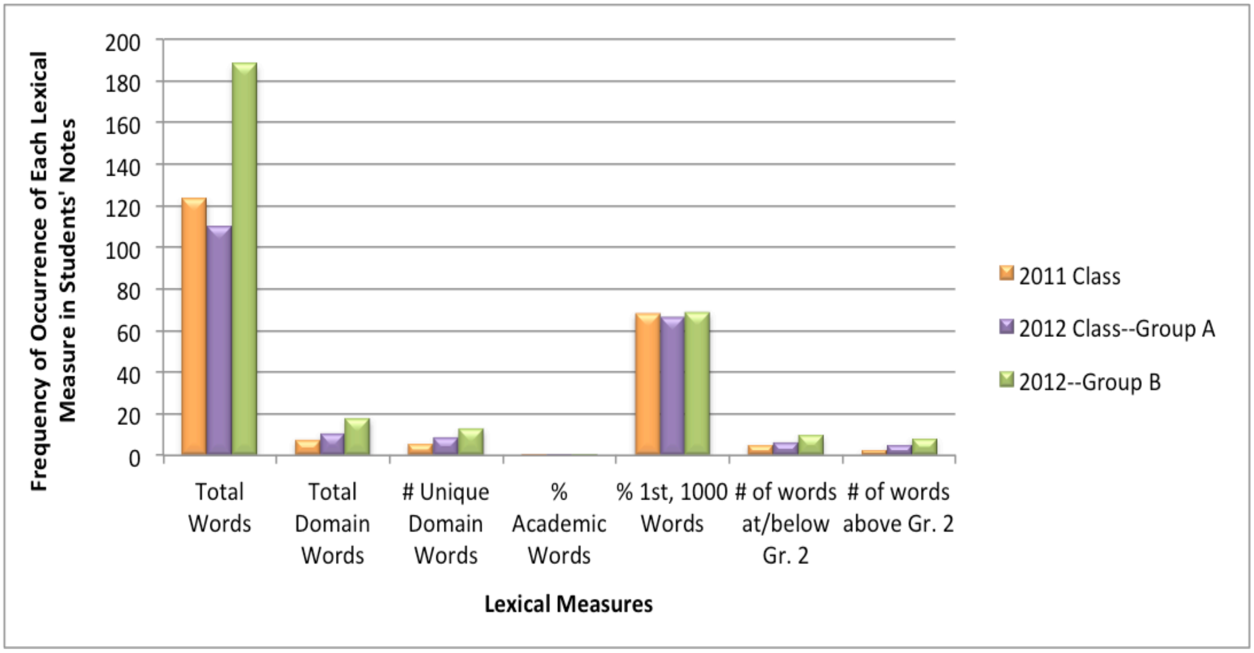

Figure 47. Means (n) across lexical measures for three student groups.

To explore significant differences across groups in student performance on behavioral and lexical measures, as well as on their knowledge advancement scores, a one-way ANOVA was conducted for each measure. Results show significant differences for the following measures: total domain words, $F(2, 39) = 8.03$, $p < .01$; unique domain words ($F(2, 39) = 7.38$, $p < .01$; total words F(2,

Table 9

Means (SD) for Behavioral and Lexical Measures for Three Groups

Behavioral Measures	**2011 Class**	**2012 Class-Group A**	**2012-Group B**
# of Notes Written	11.43 *(6.72)*	9.64 *(4.52)*	13.36 *(4.52)*
% of Notes Read	17.72 *(12.23)*	12.80 *(7.91)*	14.34 *(6.07)*
Lexical Measures	**2011 Class**	**2012 Class-Group A**	**2012-Group B**
Total Words	123.52 *(69.16)*	109.73 *(62.02)*	182.36 *(84.78)*
Total Domain Words	7.76 *(5.85)*	10.82 *(5.47)*	17.45 *(8.80)*
# Unique Domain Words	5.95 *(4.42)*	8.55 *(3.93)*	12.55 *(5.79)*
% Academic Words	0.34 *(0.54)*	0.54 *(0.68)*	0.45 *(0.54)*
% 1st, 1000 Words	68.53 *(9.02)*	66.53 *(6.92)*	66.78 *(10.30)*
# of words at/below Gr. 2	5.29 *(4.06)*	6.36 *(2.78)*	9.82 *(5.51)*
# of words above Gr. 2	2.57 *(1.83)*	5.45 *(4.08)*	7.91 *(4.72)*

Participants (n = 42)

39) = 3.69, $p < .05$; use of words at/below Grade 2 $F(2, 39) = 3.82$, $p < .05$; and use of words above Grade 2, $F(2, 39) = 11.45$, $p < .001$. Post-hoc tests (Tukey HSD) revealed that Group B used significantly more domain words in total than the 2011 class ($p < .01$, Cohen's $d = 8.21$) as well as Group A ($p < .05$, Cohen's $d = 6.47$), and more unique domain words ($p < .01$, Cohen's $d = 5.38$) than the benchmark class. Furthermore, Group B wrote significantly more words than Group A ($p < .05$, Cohen's $d = 70.01$), and Group B also outperformed the 2011 class with respect to use of words at/below Grade 2 ($p < .05$, Cohen's $d = 5.27$) as well as above Grade 2 ($p < .01$, Cohen's $d = 4.04$). These results suggest that formative feedback that is embedded in Knowledge Building practice helps young students to use increasingly rich and diverse vocabulary. These findings also suggest that visualizations reflecting student contribution patterns to group discourse prompt students to write more in total.

Findings also show that differences in vocabulary use correspond to greater achievements in knowledge advancement. As outlined in Section 5.4.4 of the previous chapter, primary analysis of this data revealed that there was a significant difference with respect to knowledge advancement between the 2011 class and both groups in the 2012 class in regard to "scientificness" ($F(2, 38) = 11.14$, $p < .001$) and "epistemic complexity" ($F(2, 38) = 3.37$, $p < .05$), with post-hoc tests (HSD) revealing that both subgroups from the Grade 2, 2012 class performed better than the Grade 2, 2011 class on "scientificness" ($p < .01$, Cohen's $d = 0.59$) and complexity ($p < .05$, Cohen's $d = 0.39$), respectively. This suggests that formative feedback coupled with collaborative reflective discussion can help students construct and communicate ideas in writing that reflect greater scientific accuracy and more elaborate explanations. Within the 2012 class, Group B wrote significantly more words than Group A, as noted, yet there was no significant difference in knowledge advancement measures between the two Group A or B ($M = 2.61$, $SD = .67$ vs. $M = 2.51$, $SD = .24$, either for "scientificness"; $M = 1.68$, $SD = .38$ vs. $M =$

1.72, *SD* = .49, or for epistemic complexity, respectively). The higher standard deviation for Group A indicates that within this group, a small number of students stood out as having especially high knowledge advancement scores, which helps to explain group performance on this measure. A more in-depth evaluation of the content of student writing, as well as analysis of the group conversation that occurs as students explore such feedback, is required to explain effects of contribution-based visualizations to students' written engagement, and indicates a fruitful direction for future research.

6.5.2 To what extent was vocabulary distributed in the shared discourse?

The continual give and take of ideas to advance community knowledge is a foundational principle upon which Knowledge Building communities operate. In order to explore group-level dynamics in the community and the shared discourse, network structure analysis was conducted using KBDeX. As elaborated in a previous section, typical Knowledge Building sessions in both Grade 2 classes involved students splitting up into rotating groups. However, all students in both classes worked in the same knowledge space on the database and contributed their ideas to a shared online discourse. For this reason, group-level analysis was conducted across the 2011 and the 2012 class as a whole with this tool.

As Table 10 shows, students in the experimental class exhibited greater degree centrality (DC) and closeness centrality (CC) than the benchmark class. For example, Degree Centrality indicates the number of connections a student has with other students using those same terms—the more connections, the more centralized he or she is in the discursive network. Thus, a greater number of students in the 2012 class were more centralized in the discourse than in the 2011 class. Additionally, more students in the 2012 class were more tightly connected to each other

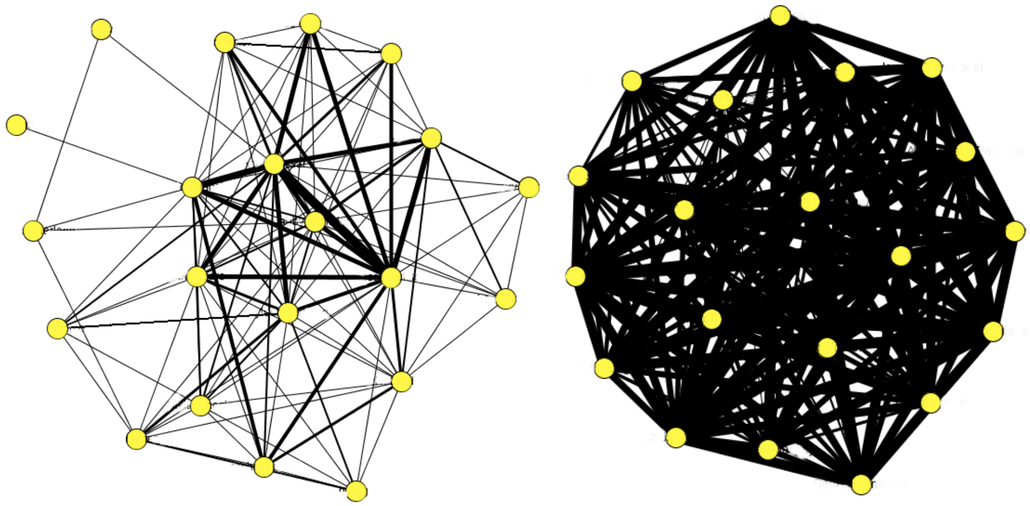

Figure 48. Network structure of students in the 2011 class (left) and 2012 class (right), with connections fostered through extent of common vocabulary.

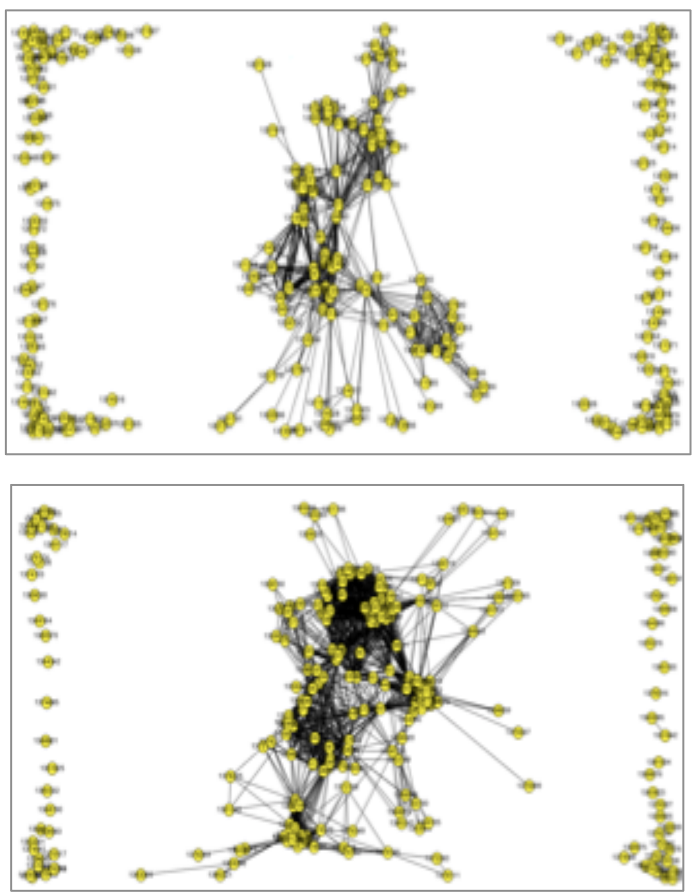

Figure 49. Network structure of notes by students in the 2011 class (top) and 2012 class (bottom), with connections fostered by co-occurrence of words in unique notes.

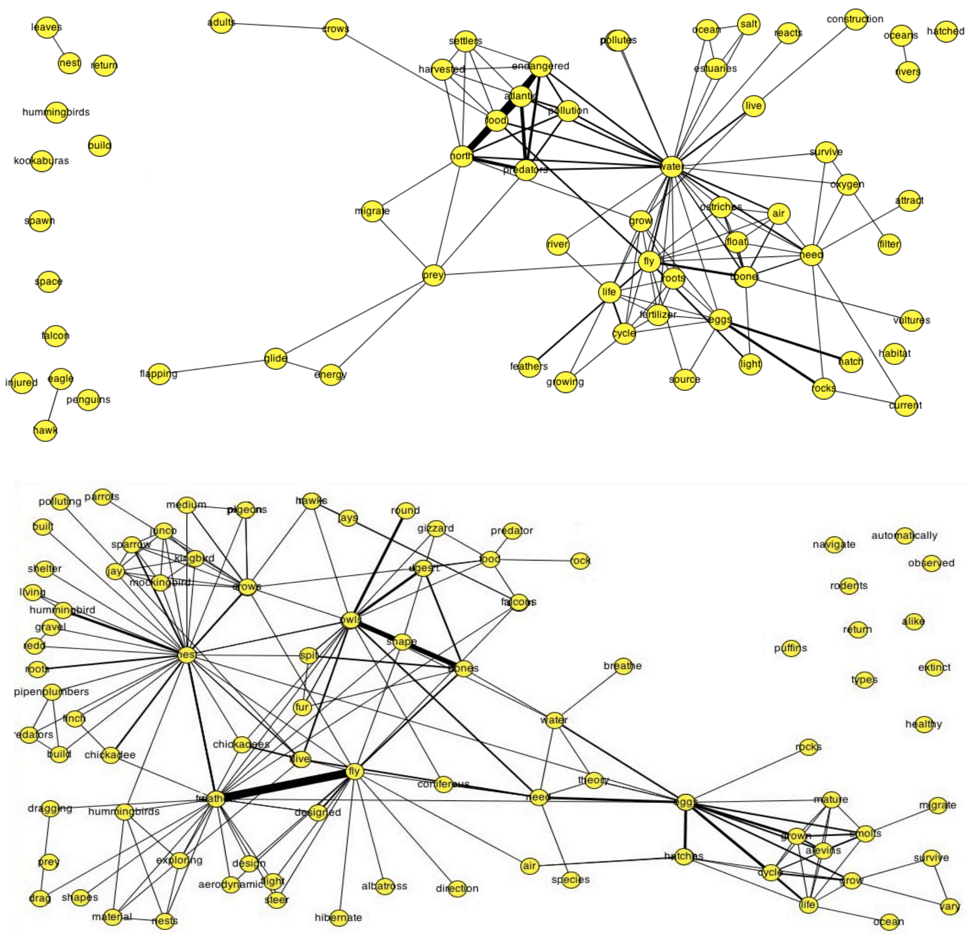

Figure 50. Network structure of words in the 2011 class (top) and 2012 class (bottom), with connections fostered by common presence in unique discourse units.

in their discourse, using more terms that were common among more students (see Figure 48). That there was greater betweenness centrality in the 2011 means that students were more dispersed in terms of their use of particular words, with more separation of social clusters engaging in different streams of discussion. At the level of notes, the experimental class students showed greater degree, betweenness and closeness centrality. So, written notes in the experimental class showed a higher number of verbal connections to other notes, indicating that the terms were being used consistently throughout students' writing (see Figure 49). Students in the 2012 class also wrote more notes that contained two or more words in a single utterance that were being used across a wider range of discussions, thus linking these discussions discursively.

Table 10.

Means of Degree, Betweenness and Closeness Centrality for Three Groups.

	Degree Centrality		Betweenness Centrality		Closeness Centrality	
	2011	2012	2011	2012	2011	2012
Students	0.80	0.98	0.01	0.00	0.85	0.98
Notes	0.02	0.06	0.00	0.00	0.01	0.01
Words	0.06	0.04	0.01	0.02	0.04	0.06

Participants (*n* = 42)

Last, while the range of key terms was wider for the 2012 class, these words were more closely connected semantically than those that characterized the discourse of the 2011 class. Finally, in terms of the interactions amongst the words themselves, the benchmark class used terms that were more "popular," in that particular words elicited a higher number of connections to other words. One explanation could be that, because the number of total domain and academic words are much smaller in the benchmark class, the distribution of novel words was lower, and so the popularity of available terms increased. Accordingly, students in the experimental class used a much higher number of words that had more diverse set of connections with other words (see Figure 50). With respect to mean level of betweenness centrality, the 2012 class used more connector words that served as "gateways" that created new links between various word clusters. That the 2012 class exhibited a greater closeness centrality on this measure indicates that while the diversity of words was greater, these words remained semantically related to one another.

While the means outlined above provide a useful description of each class, in order to explore any significant differences across classes with respect to the degree, betweenness and closeness centrality of the social network, a one-way ANOVA was conducted with students serving as the unit of analysis. A significant difference was found for both degree centrality $F(2, 39) = 10.78$, $p < .00$, betweenness centrality $F(2, 39) = 12.16$, $p < .0001$, as well as closeness centrality $F(2, 39) = 15.06$, $p < .0001$. Post-hoc tests (Tukey HSD) showed that both Groups A (*p*

< .01, Cohen's d = .16) and B (p < .001, Cohen's d = .18) displayed greater degree centrality and closeness centrality (p < .0001, Cohen's d = .1) than the 2011 class. Furthermore, the benchmark class showed greater betweenness centrality than both Group A (p < .001, Cohen's d = .0091) and Group B (p < .001, Cohen's d = .0090). These findings indicate that the 2012 class

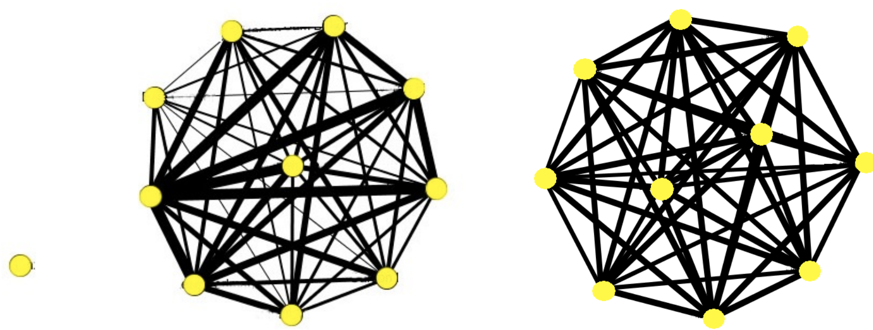

Figure 51. Network structure of students in Group A (left) and Group B (right), 2012.

community had a higher number of students who had a higher number of connections with other students, suggesting that a greater number of students were using more shared words more often. Moreover, a higher betweenness centrality indicates that there were more social clusters in the 2011 class, as opposed to the 2012 class in which each student was more highly connected to every other student. Accordingly, students in the experimental class were also more closely linked to one another in terms of the language they were using than the benchmark group. This is notable since research has shown that that network actors who exhibit more connections to other actors are more likely to receive information, and are also more likely to exert influence on others, whereas actors who are peripheral or isolated in the network are less likely to access resources and be involved in discussion (Haythornthwaite & Gruzd, 2012). Having a greater number of centralized students thus suggests that more participants were more deeply integrated into the discourse, and also had more opportunity to impact group discussion in some way.

Furthermore, as Figure 47 indicates, the experimental class shows a denser network with respect to how many relationships are formed between students. Density reveals how information flows throughout a network—less dense networks possess fewer paths for information or knowledge exchange, while higher density networks feature a higher number of paths that make possible faster circulation of shared resources (see Haythornthwaite, 2010; Haythornthwaite & Gruzd, 2012). Analysis described above shows that a larger and more diverse vocabulary set characterizes the experimental class, and, although no official quantitative test for density was performed, it appears that rather than serving to separate students into discursive cliques, the diversity of discourse seems to foster more connections between students as they pooled their knowledge and use shared language in their writing. It is important to note the fact that the 2011 class also exhibits a highly connected community—albeit to a lesser degree than the 2012 class—which indicates that Knowledge Building practices are themselves conducive to knowledge distribution across the community. In general, these results suggest Knowledge Building students are capable of creating networks that are rich in "social capital"—which, from a social network perspective, refers to a network that "hold[s] within their membership the social means to respond in need" (Haythornthwaite & de Laat, 2012, p. 355). In addition, these findings show that—even for children as young as Grade 2—as students learn and use a more diverse range of words in the context of Knowledge Building, the more discursively connected they become, and the greater the vocabulary knowledge distribution across the community.

In addition to exploring connections between students themselves, we also wanted to trace significant differences in the network structure of individual words in students' writing. In order to do this, the same series of tests as above were conducted, this time focusing on key words rather than students as actors. A significant difference across groups was found for closeness centrality, $F(2, 43) = 3.34$, $p < .05$, with the students in Group B using terms that were more semantically bound together in their discourse than either of the other groups. As previously reported, this group of students exhibited more diverse vocabulary than the other two groups. Having a discourse that is diverse as well as semantically connected is desirable and represents a condition that is conducive to vocabulary learning, as students have access to a wider range of vocabulary in a collective knowledge pool. This condition can foster higher levels of word-associations that lead to use of these terms in different contexts. In terms of degree centrality and betweenness centrality, no significant differences were found. This suggests that engagement in Knowledge Building practices encourages active use of important vocabulary in writing and making connections across various discursive streams in collective dialogue.

6.6 How did students respond to the formative feedback?

With respect to the usability of the feedback presented to the Grade 2 children, students were able to read and interpret the Word Cloud visualizations quite easily, and recognized the difference between the three types of Clouds they were shown ("Our Words," "Expert Words," and "Our Shared Words"). Students did not have trouble identifying challenging words, and would typically gesture towards and read the words they did not recognize out loud two or three times. A total of 36% of the words featured on the Expert word cloud were also present the students' online dialogue (e.g. "gizzard," "parr," "redd," "drag," "aerodynamic," "navigate," etc.). On more than one occasion, after metadiscourse discussion time was over and students could move onto writing in the database, they formed small groups or paired off to seek out resources that could help them learn more about the important terms they just discussed. For example, in the January 12th metadiscourse session, two students noticed that term "drag" on the word cloud. After the "KB talk," these ran up to the Word Cloud to get a closer look and to touch the words they did not recognize. Students then grabbed a book from the classroom and entered a definition into the database: "*Important Information + Source: When a bird is dragging their* *feathers it is slowing itself down. It is called a drag.*" Shortly following another student added the question: "*I need to understand: What do birds use to make a drag?*" This same student also posed a theory about the concept: "*My theory: I think that bird's drag on walls.*" Students in this case did not advance far beyond introducing a simple definition and proposing an initial idea about the concept of "drag." However, this example gives evidence of their interest in working to integrate new and challenging vocabulary into their discourse and, perhaps more importantly, their effort to build onto a simple definition with their own ideas. This example also shows how students might introduce and begin to use unfamiliar and difficult terms in their own discourse.

Similarly, students' use of hitherto unknown words revealed concurrently the development and limits of their understanding in both their offline and online dialogue. For example, on November 10th, a young student wrote the following note in the database: "*Bird's feathers are aerodynamic so they can fly fast.*" This simple statement implies an understanding that an aerodynamic shape is conducive to flight; however, while accurate, it does not convey a deep or elaborated understanding of the concept. Nevertheless, this utterance introduced the concept to the whole group, and the term itself, like the example above, became part of the community vocabulary that informed and fuelled the group inquiry, with other students formulating meanings about the concept as the study progressed. Take, for example, the following excerpt of a discussion that emerged from a metadiscourse session that arose during while students were viewing the "Concept Clouds":

> *Student A:* Where it says dynamic, if you add aero on the dynamics on top, on top, (gesturing), if you ad an "aero" it would be aerodynamics.
> *Teacher:* Oh! So what does that mean, aerodynamics?
> *Student B:* Oh, it's a type of fly, no, it's a type of science… right?
> *Teacher:* About what?
> *Student B*: It's a type of science that helps things float in the air.

Teacher: So you understand how things float in the air?
Student B: Ya…

This young students' understanding of the term "aerodynamics" corresponds to the third level of Stahl's (2003) four levels of word recognition, which map onto the following degrees of familiarity: i) the word has never before been encountered; ii) the word is recognized but its meaning remains unknown; iii) the word is recognized in a specific context (it has something to do with…); vi) the word is known. In this case, the student recognizes the word "aerodynamic" as 'something to do with' flight, and works to articulate what she thinks it means. While this young student is limited in her capacity to explain the concept, her attempt here suggests she possesses an appreciation of the concept not simply as a statement of fact, but as a *way of understanding* flight. Indeed, meanings of words grow over time, as multiple and varied encounters with a word in context helps to introduce a range of information about that word that can be used to create more comprehensive and meaningful understandings. Moreover, as Stahl explains, "The information that overlaps between encounters is what is important about the word...with repeated exposures the connections become strengthened as that information is found in repeated contexts and become the way the word is "defined" (p. 18-19). In this example, the young students' response hints at an awareness of the complexity of the concept, an awareness that could prove a fruitful foundation for the development of a deeper, more nuanced understanding of the term.

As these examples show, students were not discouraged by new and challenging words they did not understand, but repeatedly took an interest in discovering the meaning behind unfamiliar "expert" terms. They also worked to build an understanding of these new words in relation to their inquiry, embedding them meaningfully within an existing dialogue that helped them to make sense of these challenging terms in the context of their Knowledge Building work.

6.7 Implications of findings for classroom practice

Results show that formative feedback that is productively integrated into authentic inquiry practices can facilitate vocabulary growth, use of new words in students' writing, and advances in community knowledge. On the whole, students in the experimental class used more domain-specific vocabulary more often and exhibited greater "scientificness" and "epistemic complexity" of ideas than students in the benchmark class. Within the experimental class, students who received formative feedback related to both vocabulary use as well as feedback regarding the various ways they were contributing to group dialogue used more sophisticated words than students who only received feedback regarding vocabulary, but did not show greater knowledge advancement. This suggests that the vocabulary use for students receiving both kinds of feedback extended more widely beyond their theorizing work and into different contribution types, such as asking questions or reporting facts. It also suggests that engaging students in rich reflective discussion around formative feedback can have a positive effect on students' knowledge advancement, as both experimental groups performed equally well in this regard.

Based on these findings, one possible recommendation for primary grade teachers is to encourage group reflection consistently throughout a Knowledge Building study, since metadiscourse sessions proved fruitful even for students as young as Grade 2. Another recommendation is that teachers take advantage of group discussion periods to integrate feedback visuals for students to collaboratively explore. Finally, network structure analysis of students' collective discourse showed that all students in the experimental class were more discursively connected to one another and made more connections with other students via their shared discourse than students in the benchmark class. That this distribution of vocabulary knowledge is evident in Grade 2 is promising given that the disparity between students who demonstrate high literacy skills and those who show lower level skills accelerates notably after the primary level and into the junior grades (Stanovich, 2000). Results also suggest the importance of supporting metadiscourse, enhanced by formative feedback, as a routine component of Knowledge Building practice with young students.

Further research that explores students' verbal dialogue in addition to the content of their online contributions is needed to more fully explore and assess primary aged students' literacy levels and capacities for expanding vocabulary knowledge within the context of Knowledge Building practice. Also, to better understand the impact of formative feedback on developing students' capacities in literacy concurrent with creating new knowledge, future research should focus on refining feedback designs and examining a wider range of literacy and knowledge distribution indicators. Future studies in this area would also require more rigorous analysis to determine growth in accuracy of word use with respect to key vocabulary, in order to ascertain the extent to which increase in vocabulary repertoire corresponds to correct use of terminology and knowledge advancement.

6.8 Chapter Summary

This chapter described secondary analysis of data generated from Design Cycle 1 that explores the impact of formative feedback visualizations embedded within Knowledge Building practices on students' vocabulary use and knowledge. First, literature that explores conditions conducive for expanding vocabulary knowledge was reviewed. Next, the participants, dataset and plan of analysis for the study were described. Following this, I reported the results of the research, including considerations of growth in student vocabulary repertoire and extent of vocabulary knowledge distribution on a group level. More specifically, findings revealed that 2012 class used significantly more words above Grade 2 than the 2011 class, and experimental Group B from the 2012 class used more total and unique domain words than the 2011 class.

Within the 2012 class, Group B wrote significantly more words than Group A. Both Groups in the 2012 class, however, showed higher knowledge advancement scores than the 2011 class.

Results from social network structure analysis showed that both Groups A and B displayed greater degree and closeness centrality than the benchmark 2011 class. Furthermore, the 2011 class showed greater betweenness centrality than both Group A and Group B. In general, these findings indicate that as students learn and use a more diverse range of words as a component of their Knowledge Building practice, the more discursively connected they become, and the greater the vocabulary knowledge distribution across the community. Analysis on the network structure of individual words showed a significant difference across groups for closeness centrality, with the students in Group B using terms that were more semantically bound together in their discourse than in either of the other groups. That Group B's discourse was also most diverse in terms of key vocabulary suggests these students were making active use of important terms in their writing and were making connections across various discursive streams in their shared discourse.

Following a more detailed description of the findings briefly outlined above, I offered some qualitative observations regarding student use and interaction with the formative feedback tested in the study—namely, that students reacted favourably to being confronted with new and challenging words they did not recognize, and repeatedly took an interest in discovering the meaning behind new "expert" terms. They also consistently put effort into building an understanding of new words, and worked to embed them meaningfully within their dialogue throughout the length of their inquiry. Finally, I concluded the chapter by briefly commenting on the implications of the findings for classroom practice.

CHAPTER 7: DESIGN CYCLE 2: ENHANCING THE EFFECT OF FORMATIVE FEEDBACK ON WAYS OF CONTRIBUTING TO EXPLANATION-SEEKING DIALOGUE IN GRADE 2

7.1 Chapter Overview

In light of the successes and weaknesses of the treatments conducted in Design Cycle 1, a revised plan was composed for Design Cycle 2. Changes to the study design are laid out in this chapter, which runs as follows: i) a discussion about the "Big Ideas" in the Grade 2 curriculum; ii) a description of new design components oriented to help students probe these "Big Ideas" for Design Cycle 2, iii) an explanation of how the new study elements fit into the overall principle-based design; iv) an outline of the participants and dataset; v) a description of methodology used for the study; vi) a summary of results; vii) last, a discussion about the implications of the study findings and a commentary on lessons learned from this second iteration of research.[4]

7.2 Co-Designing the Knowledge Building Inquiries

The study described in this chapter attempts to reproduce and improve on the findings derived from research conducted in Design Cycle 1, and assess the extent to which young students' ways of contributing to explanation-seeking dialogue can be enriched through principle-based educational treatments implemented within the context of authentic Knowledge Building practice. In order to realize this objective, the plan for Design Cycle 2 includes a number of refinements and changes to the treatments as a result of lessons learned from Design Cycle 1. These changes are described in detail in the following section.

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[4] Again, a component of the research discussed in this chapter was presented at the 2013 Knowledge Building Summer Institute "Building Cultural Capacity for Innovation", and will be published in the conference proceedings. However, in this chapter I elaborate substantially on a number of sections, including study design and data analysis.

7.2.1 Refinements to Design Cycle 2: Targeting the "Big Ideas" in the "Understandings Life Systems" stream

Developing supports to help expand students' contribution repertoire represents a central goal of this research. The value of such innovations lies to a great extent in their capacity to support greater knowledge advancement for the community. Thus, articulating a clearer focus for the ideas and concepts students need to grasp helps researchers to assess the potential of these new tools and approaches for facilitating conceptual understanding and deepening knowledge. In this design cycle, the main units of study remained the same as in Design Cycle 1: students participated in two Knowledge Building units under the "Understanding Life Systems" stream, with a focus on "Growth and Changes in Animals," particularly birds and salmon. However, for this iteration, the focus was on helping students engage more deeply with the "Big Ideas" that correspond to the "Understanding Life Systems" stream. These "Big Ideas" are described in the Ontario Curriculum Standards (2007) documents as follows:

1. Animals have distinct characteristics
2. Humans are animals. There are similarities and differences among different kinds of animals.
3. Humans need to protect animals and the places where they live (p. 58).

As outlined in the curriculum, these "Big Ideas" map onto overall expectations for Grade 2, which call for students to be able to:

1. Assess ways in which animals have an impact on society and the environment, and ways in which humans have an impact upon animals and the places where they live.
2. Investigate similarities and differences in the characteristics of various animals.
3. Demonstrate an understanding that animals grow and change and have distinct characteristics (p. 58).

The curriculum guidelines outline two expectation targets associated with these “Big Ideas” that represent a standard level of understanding that Grade 2 students are expected to achieve. These expectations correspond to the theme of ‘structure and function’ in biology and encompass ideas related to evolution and adaptation. More specifically, they stipulate that students need to be able to “identify and describe major physical characteristics of different types of animals“ as well as “describe an adaptation as a characteristic body part, shape or behaviour that helps a plant or animal survive in its environment” (Ontario Curriculum Standards, 2007, p. 60).

Helping students to develop an understanding of these complex ideas is important for preparing them for the study of science at higher grade levels. For instance, the “Understanding Life Systems” curriculum stream is a direct precursor to more advanced studies in Biology, officially beginning in Grade 9. Studies show that possessing knowledge of concepts related to evolution and origins of species is important for understanding concepts in contemporary biology (Mayr, 1991). Thus, if children can begin to understand the mechanisms of adaptation at an early age, this can help them to develop a sense of evolutionary biology that they can build upon as they advance to later grades.

In what follows, I explore the extent to which the Grade 2, 2012 class demonstrated an understanding of these themes and ideas, beginning with a discussion about their achievements in understanding ideas related to the biological “structure and function” of birds and salmon. This discussion is engaged in light of existing research on young students’ capacity to understand biological concepts. Exploring the level of understanding demonstrated in the discourse of the Grade 2, 2012 class in relation to important evolutionary concepts will provide a benchmark that can be used to compare and assess the extent of knowledge advancement evidenced by the students participating in Design Cycle 2.

7.2.2 From a "naive biology" to deep understanding

As described, the two curriculum targets corresponding to the theme of 'structure and function' call for students to describe different physical characteristics of animals and describe how certain body parts or behaviors helps an animal survive in its habitat. In the Grade 2, 2012 class, students' repeatedly demonstrated their ability to describe how certain behaviours help birds and salmon to survive. Consider this excerpt of an in-class discussion that took place during a "KB talk" in which one student posed a question to the group about salmon behaviour:

> *Student A*: "When salmon they swim to the salt water, do they move when they're babies or adults? They're smolts when they move."
> *Student B*: "They need to grow in river water, and when they swim to the ocean they have to be bigger, but if they are tiny it will be harder for them to survive because there are bigger things in the ocean and it can eat them."
> *Student C*: "I'm adding onto [Student B] – so then why do they ever go to the sea? Because like, if they want to survive, why don't they just stay in the river?"
> *Student B*: "I think because some of the time the water gets warm, and so they, sometimes they have to move because the salt water is colder."

In this example, students participate in an informed discussion about the possible causes of salmon migration, offering plausible theories and ideas to explain particular aspects of salmon behaviour. Moreover, students were also able to identify and connect the importance of an organism's anatomy to their ability to survive in a particular environment. For example, in this episode of conversation, students talk about why fish live in the water.

> *Student A*: Why do fish live underwater? I don't know why they do that.
> *Student B*: They were born to be in water, they were born in water, and they're designed to breath underwater and swim.
> *Student C*: They can't breathe on land.
> *Teacher*: What do they breathe?
> *Student B*: They breathe, it's basically the opposite. We can't breathe underwater for a long time and they can but they can't breathe in air.

Teacher: What part of their body allows them to…
Class – GILLS!
Student B: They go up down up down [*gesturing with his arms to mimic movement of gills*].

As with the previous example, this excerpt illustrates young students' capacities to probe and respond to important issues involving animal behaviour and characteristics. However, this small excerpt is also reflective of a more general pattern in students' discourse—namely, the difficulty they have in probing questions that evoke evolutionary ideas, such as "why do fish live underwater," in ways that extend past already known facts (for instance, the fact that fish are born in water, or that fish can breathe underwater). For instance, while Student B's claim that fish are "designed" to be in water is provocative to the educator or researcher, the students themselves do not interrogate the idea. The discourse does not advance beyond the fact that "fish are born to be in water" to investigate more deeply problems such as how fish came to possess gills, how other types of sea creatures without gills manage to breathe underwater, how different types of fish might have changed over time, etc. As this example reveals, students demonstrate the capacity to ask questions that evoke evolutionary ideas, however, they also show a limitation in their ability to sustain a conversation that explores these ideas in deep ways.

That these students exhibit such limitations is not surprising. A considerable body of research shows that achieving an understanding of Darwinian evolutionary thinking can be very difficult for both young students as well as adolescents and adults—even those including students in advanced biology and medicine (Almquist & Cronin, 1988). As this body of literature shows, adults and advanced students often exhibit a range of misconceptions and misunderstandings when it comes to demonstrating knowledge of species' origins as well as adaptation, ranging from an explicit rejection of Darwinian concepts (Almquist & Cronin, 1988) to consistent and long-lasting misinterpretation of important ideas like natural selection (e.g.

Brumby, 1979; Bishop & Andersen, 1990; Greene, 1990). In cases where individuals exhibit some understandings of evolutionary biology, these typically reflect a Lamarckian rather than a Darwinian view of adaptation (e.g. Evans, 2001; Ferrari & Chi, 1998).

Similarly, a growing body of research exploring children's intuitive interpretation of the biological world and their reasoning about biological phenomena focuses on both understanding the capacity for young children to understand biological concepts and investigating how persistent biological misconceptions might arise (e.g. Carey, 1985; Hatano & Inagaki, 1996; Keil, 1994; Wellman & Gelman, 1998). For instance, in a study exploring young children's intuitive biological knowledge-systems, Inagaki and Hatano (2006) argue that children as young as 5 years old "possess a theory-like knowledge system that can be called naive biology, which involves a set of causal devices enabling children to offer coherent predictions and explanations for biological phenomena" (p. 177). Similarly, developmental theorists (e.g. Gelman, 1990) argue that even without much experience, children are predisposed to notice particular aspects of a certain environment or of a living thing (e.g. the gills of a fish move up and down when it "breathes"), and intuitively generate and consider their own interpretations based on these observations. These tendencies help children to build a "naive biology" at quite an early age (Inagaki & Hatano, 2006, p. 178).

While small children show the capacity for biological understanding, limitations are also evident. For instance, a characteristic of this "naive biology," particularly in regard to children five to seven years of age, is to choose vitalistic over intentional or physiological explanations of animal behaviour and change (Inagaki & Hatano, 2006). In other words, children's intuitive theories about evolution often involve the idea that animals and other living things adapt to their environmental niche, often over generations, in order to stay alive and propagate. According to this framework, an animal's bodily characteristics, functions and behaviours exist and operate solely in order to maintain life. Other research focusing on children's biological understanding shows similar limitations in understanding of biological causal mechanisms, such as genetic inheritance (Backscheider, Shatz, & Gelman, 1993; Rosengran, Gelman, Kalish, & McCormick, 1991). Thus, while young students possess capacities to understand biological concepts at a young age, they can often hang onto misconceptions generated at earlier ages well into their adulthood. Misconceptions related to a biological causal framework—including ideas associated with genetics, adaptation, and evolution—seem to be particularly sticky.

Studying children in a slightly older age group, Samarapungavan and Wiers (1997) researched the intuitive concepts of speciation apparent in the ideas of children 8-13 years old to determine whether their concepts about biological evolution demonstrated explanatory coherence (Thagard, 1989). More specifically, the researchers were interested in whether children exhibited coherent explanatory frameworks when asked to offer specific solutions to problems of speciation—namely problems related to the origins of life and to mechanisms of change in species over time. Basing their exploration off the work of Mayr (1982), Samarapungavan and Weirs proposed four types of explanatory frameworks that children would likely demonstrate in their ideas about speciation: i) Non-Evolutionary—which purports that species do not transform; ii.) Hybridizationist—which explains speciation as the result of species intermixing; iii.) Micro-Evolutionary—which allows for small changes to occur within a single species iv.) Macro-Evolutionary—which includes both Lamarckian and Darwinian biological concepts. The researchers hypothesized that students would be able to demonstrate coherent frameworks, but that, having received no formal education in evolutionary biology, most would reflect non-evolutionary ideas.

The researchers found that 80% of students used coherent frameworks in their responses. The majority of students (48.57%) held views that mapped onto non-evolutionary framework, 22.86% of students expressed micro-evolutionary ideas, and 8.57% of students expressed macro-evolutionary views. No significant differences were found for types of explanatory frameworks demonstrated across ages. Of the students who expressed macro-evolutionary views, all students reflected Lamarckian ideas of evolution. No student demonstrated a Darwinian framework in their ideas. As noted by the researchers, not only did no students show notions of Darwinian ideas, but the fact of inter-species variability was found to be of very little importance in general.

These findings support the results Evan (2000) reports in her study on the emergence of understanding of the origins of species in elementary school children between the ages of 5-12. In this research, Evans explored the conditions under which students express natural as opposed to intentional or teleo-vitalistic explanations of species origins. Four explanation types were used to evaluate students' ideas, which map onto those used by Samarapungavan and Weirs (1997): i) Spontaneous Generationist; ii) Creationist; iii) Evolutionist; iv) Hybridizatonist. Unlike the previous study, Evans found an apparent developmental trend across ages with respect to depth of ideas on origins of species. More specifically, older students (ages 11-12) were more likely to evoke an evolutionist response; children in junior (ages 8-9) and primary grades (ages 6-7) tended to express non-evolutionary views; eight and nine year olds were more likely to express "creationist" ideas—the notion that God created creates as they are; and six and seven year olds tended to explain species origins with ideas corresponding to a "spontaneous generation" viewpoint—the idea that species arise fully formed by some mysterious process. Hybridizationist views were found to be extremely rare in any age group. Furthermore, when assessing students naturally occurring conceptions about mechanisms of change, Evans grouped student responses in three explanatory categories—i) volitional or intentional, which implies a teleo-vitalistic view; ii) Lamarckian, which includes ideas related physiological changes attributed to genetic inheritance; and iii) Darwinian, which includes responses that consider inter-species variation and natural selection. As in the previous study, those children that demonstrated evolutionist responses were more likely to refer to Lamarckian concepts than Darwinian ideas. In fact, only one student out of the 50 participants exhibited Darwinian concepts when considering mechanisms of change in animals. Taken together, these studies highlight the common misconceptions and beliefs that characterize young children's intuitive conceptions of evolutionary biology. As Samarapungavan and Weirs (1997) point out, he development of novice explanatory frameworks at a very early age can make it very difficult for students to restructure those frameworks to integrate Darwinian concepts through traditional instruction in evolutionary biology (p. 172).

So, what might it take to help children move past a "naive biology" to a more developed understanding of evolution and adaptation? Literature dedicated to investigating this question suggests that there exists "more than one route" to helping develop children's capacities to build evolutionary explanations (Evans, 2001, p. 260). It was hypothesize that helping students create coherent explanations that engage challenging biological concepts can be done through supporting their ability to contribute diversely to their collaborative explanation-seeking discourse, with a focus on helping students obtain useful information, synthesize ideas, and continually reflect on their progress.

Another line of inquiry engaged by the Grade 2, 2012 students is useful to discuss here, not only because it illustrates both the limitations of students' biological understanding, such as those identified in the referenced research, but also because it reveals that students themselves are aware when their ideas are lacking and need to be improved. For example, during a metadiscourse discussion conducted near the middle of the inquiry on salmon, a student responded to a query that was posted in the database in the early stages: "The question I was going to answer was why do salmon lay eggs? Salmon lay eggs because it's part of their life cycle and because the mother salmon needs to lay the eggs." Similar to the example above, this student responds to the question at hand with two scientifically accurate statements of fact. This response bears resemblance to other theories about this question that were contributed by students throughout the course of the inquiry. The following ideas, each made by different students and contributed to the online discourse over the course of approximately eight weeks, include: "*Because they need more species"; "They need to lay eggs so they can make more eggs*" "*They need to lay eggs because it makes more salmon"; "Because they need more species"; "So there is enough fish"; "Because they want kids.*" As these examples show, although students stayed engaged with this question throughout a prolonged period of time, their ideas remained very similar. Students had a hard time moving beyond a "teleo-vitalistic" theory—one concerned with the notion that animals behave in certain ways in order to perpetuate life—to one that expanded to include considerations of adaptation or evolution in explanations of the behaviour of egg-laying.

Although students did not make much progress in their theories about this question, their dissatisfaction with the ideas they had generated became evident by the manner in which this question kept remerging in group discussions. For example, the question of "why salmon lay eggs" resurfaced once again during a metadiscourse session that took place about two weeks before the end of the salmon unit:

> *Teacher:* There it is again. Why do salmon lay eggs? What's so tricky about that question?
> *Student A:* Why do salmon lay eggs? Well it's sort of the same as birds, and with everything that lays an egg. Well, WHY do birds lay eggs? WHY do salmon lay eggs?

As video of this discussion shows, this student gestures with her arm at each "why" as if to emphasize that this dimension of the question still has not been addressed to her satisfaction.

What she is emphasizing, it seems, is the difference between the questions "Why do salmon reproduce?" and "why do salmon (and other animals like birds) reproduce *in this particular way*?" By making an explicit connection between the similar traits of salmon and birds, this student is expanding the framework with which her community can think about the causes of these reproductive behaviours. She both points towards the knowledge gaps that exist in her community's inquiry, while at the same time (and perhaps unintentionally) provides her community with a framework that could help them think of ideas beyond those they have already generated, which predominantly involved the perpetuation of the species. Most certainly, part of this framework would involve deeper inquiry into evolutionary concepts and engage the "Big Ideas" of this curricular stream.

So, although students have a difficult time engaging deeply with the more counter-intuitive aspects of questions involving animal behaviour and characteristics, they show the capacity to identify when deeper and more coherent theories are needed beyond those that the community has already generated. The aim of the second design cycle would be to help students develop ideas beyond the extent of those demonstrated by the Grade 2, 2012 class in this curriculum area.

7.2.3 Creating a principle-based design: Refinements to Design Cycle 1.

The following sections outline the plan that was created in order to refine the initial study design in a way that that remained dedicated to enacting Knowledge Building principles, and that was geared towards helping Grade 2 Knowledge Builders collaboratively advance their understanding of the "Big Ideas" in the curriculum unit. The Knowledge Building principles around which Design Cycle 1 was based remain the foundation of Design Cycle 2, including *knowledge building discourse, constructive use of authoritative sources, concurrent,* *transformative and embedded assessment, emergent knowledge, symmetrical knowledge advancement.* However, a sixth principle was included—*rise-above*—as an emphasis in this second design cycle (see Chapter 2, Section 2.2.1 for an explanation of this principle). The reasons for this, as well as a description of all the refinements made to Design Cycle 1, are detailed below. Each element described represents a new component that has either been added to or has replaced an aspect of the initial design.

i) *Cognitive and Performance-Based Assessments: Initial "I Wonders" and a Final Quiz*: Additional informal assessments were integrated into the study design to enable us to evaluate the knowledge advances of students in more depth. Both cognitive and performance-based assessments were integrated into the Knowledge Building practice for both units (see Chan & van Aalst, 2004). As a first step for inquiry, students were asked to write down one or two of their most puzzling questions about birds. These questions were printed out on sheets of paper and posted on the Grade 2 "Wonder Wall." In addition to this, students were also asked to think about possible responses to these questions, and to write their ideas on a separate piece of paper. These self-generated questions, as well as the tentative responses, serve as a form of cognitive assessment that could both provide a frame for future inquiry and could expose gaps in understanding (Novak & Gowin, 1984). These question-answer sets would also provide an overview of the types of questions that the students were wondering about, and how these questions mapped onto the curriculum expectations for the for the "Understanding Life Systems" curricular stream. Also, as a form of performance-based assessment (Reeve, 2000; Metcalf, Krajcik, & Soloway, 2000), an informal quiz was conducted at the end of the year that engaged the "Big Ideas" in the curriculum area. This activity would help illustrate the extent to which students' developed their ideas over the inquiry period. Past studies have adopted similar instruments to act as summative assessment measures of students collaborative inquiry work, including the use of student-composed reflective portfolios (Scardamalia, Bereiter, & Lamon, 1994; Reeve, 2000), as well as self-explanations (Hoadley & Linn, 2000).

ii) *Our Improved Theory:* As described, the Contribution Clouds did prove not very helpful in getting students to make comparisons or synthesize ideas that were present in their discourse in Design Cycle 1. While the Contribution Clouds could inspire excitement for students who were eager to address questions visualized in a Contribution Cloud and that had remained unanswered in the online discourse, they were not so helpful for producing and sustaining a focused discussion on a given problem. So, the use of Contribution Clouds was abandoned, and instead the scaffolds were used to help students synthesize ideas and *rise above* current levels of understanding. To this end, a new scaffold was introduced to the Grade 2 database: "Our improved theory." This version of the scaffold is an adaptation of a similar scaffold, "A better theory," that is used in the scaffold sets designated for older grades in this school. As implied by the use of a plural pronoun, this adapted scaffold was meant to underscore a collective effort where the group could collaboratively reflect on their ideas and attempt to articulate a new, more advanced theory. While this scaffold would be open to individual students while they worked on the Knowledge Forum database, the class as a group would be called to engage with this scaffold during select metadiscourse sessions. During these sessions, the group would attempt to integrate ideas and facts relevant to a question that emerged in their discourse in an effort to advance community knowledge. Notes would be composed collectively and would reflect the input of the whole group. In this way, students as a group would be encouraged to review progress, synthesize ideas, and identify promising next steps as a regular component of their Knowledge Building work.

iii) *Keywords and Concept Clouds*

Because of the success of the Concept Clouds in the previous design cycle on the growth and use of students' productive written vocabulary, these visualizations were retained for the second iteration. Similarly, because KBDeX became available for use during Design Cycle 1 and provided a wonderful means of displaying relationships among vocabulary in shared discourse, this tool was used again to generate variations of the Concept Cloud visualizations for this iteration. So, there would be two types of Concepts Clouds. First, feedback about the dominant terms characterizing student discourse ("Our Words") would be created using Wordle, as in the first iteration. Use of Concept Clouds that displayed expert terminology ("Expert's Words") and that depicted the extent to which student vocabulary mapped onto expert discourse ("Our Shared Words") would also be repeated (see Figure 52).

Figure 52. Concept Clouds including "Our Words," "Experts' Words" and "Our Shared Words."

Second, feedback that displayed the semantic connections students were making between important terms in their discourse would be produced with KBDeX (see Figure 53).

Moreover, in order to have students more actively involved in the process of identifying key terms, students were encouraged to select keywords from their writing and to tag these words using the keyword feature in Knowledge Forum every time they went onto the database.

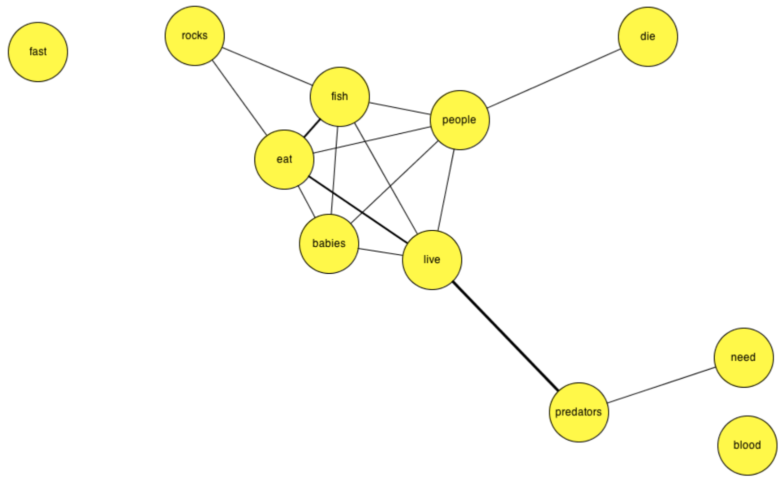

Figure 53. KBDeX visualization of domain words shared across "Birds" and "Salmon" inquiries.

Tracing the use of key words over time has been shown to help map out the presence and use of new concepts in a discourse (Sun, Zhang, & Scardamalia, 2010). Also, having students select their own keywords creates a "folksonomy" of key terms, which is a type of ontology that evolves organically from collaborative use of user-generated tags and helps to give structure to digital content (Sinclair & Cardew-Hall, 2008). By actively key-wording their own ideas, students are both reflecting on important aspects of their writing and are at the same time providing useful meta-data that can feed into automated tools—in the case of this study, the Wordle and KBDeX platforms. Similarly, the act of key-wording can take on added significance to students when they see that the ways they use the features of Knowledge Forum directly manifest into other aspects of their Knowledge Building practice, namely, the words that are featured on Concept Cloud visualizations. In addition, for researchers, possessing an aggregate list of student-generated keywords provides a useful source of data that can be used to assess the extent of semantic crossover between students' discourse, authoritative texts, and curriculum targets.

7.3 Method and Analyses

In this section I detail the participants, procedure and plan of analysis for Design Cycle 2.

7.3.1 Participants and classroom context

Participants for this study include 43 Grade 2 students (22 boys, 21 girls) from two consecutive Grade 2 classes attending EJ-ICS during the 2012 and 2013 school years. The 21 students from the Grade 2, 2012 class (11 boys and 10 girls) comprise the comparison group for this study. The experimental group consists of 22 students (11 boys and 11 girls) from the Grade 2, 2013 class.

The Knowledge Building work that was conducted by the Grade 2, 2013 students is the same as that described in the previous chapter, that is, all students completed a three month bird study and following this with another three month unit on salmon. Both classes examined similar artifacts, such as owl pellets, nests and feathers, and both classes participated in the "Lake Ontario Salmon Restoration Program" by hatching salmon eggs in their classroom tank and then releasing the alevins back into the wild with the assistance of biologists from the program. As described, the Grade 2 class typically had one 45-minute session a week dedicated to Knowledge Building. In these sessions, the class was split up into two groups in which half the students went to the library and the other half engaged in inquiry. Unlike Design Cycle 1, both of the two rotation groups in this study participated in the same design interventions. Gains in contribution diversity or depth of understanding would be traced by comparing the comparison class, constituted by the 2012 students, with the experimental class, comprised of the entire 2013 class.

7.3.2 Procedure

Both 2012 and 2013 classes engaged in collaborative discourse both on and offline.

Discussions included a series of metadiscourse sessions, in which the students reflected on the state of their Knowledge Building discourse, with the goal of deepening discussion and advancing group knowledge. Students in the Grade 2, 2013 class were introduced to the Concept Clouds and the Metadiscourse Tool from the first design intervention. Both these forms of feedback reflected work done by the whole class. A detailed breakdown of the interventions that occurred over the course of eight months is outlined in the following section.

7.3.3 Metadiscourse sessions

During the 2012-2013 school year, there were a total of seven metadiscourse discussions overall. Discussions took place throughout October until May. At the beginning of the year, metadiscourse sessions took place more closely together in order to introduce students to the scaffolds, the feedback visuals and the process of key-wording. After this, several weeks separated each metadiscourse session in order to give students ample time to engage with various aspects of their inquiry, which included the dissection of owl pellets, observation of birds in parks and other areas around the school, and the introduction of the salmon eggs into the classroom. This time also allowed students to generate and build onto ideas and theories produced in the online discourse. As in the first iteration, the intervals between interventions were not equal due to a variety of scheduling circumstances (e.g. the class play, holidays) or technological issues that affected Knowledge Building sessions and work on Knowledge Forum in the Grade 2 class. However, during gaps between metadiscourse sessions students were still engaging in research and "KB talks" as usual.

- October 3rd—Introductory session: Students were introduced to the concept of keywords, and were shown how to create keywords on Knowledge Forum. Discussion took place around the purpose of keywords so that students understood their value and function, and also understood that their own chosen keywords would constitute the makeup of the Concept Clouds they would review as the year progressed.

- October 10th—First metadiscourse session: Children reflected on the Concept Clouds as well as visualizations generated by the Metadiscourse Tool. This conversation included a special discussion targeting the use of the scaffold "important information + source," with the goal of having children articulate and acknowledge the utility of this contribution type to their group inquiry.
- October 18th—This session focused specifically on the question "where do birds come from?" This question had been posed in the online database a number of times, but had received very little feedback so far. Students were asked to reflect on their progress with respect to this question, and to think about how they could advance knowledge in this area. Students' ideas were recorded in a collective note that was contributed to the database at the end of the group discussion.
- November 1st—Our improved theory: This discussion was focused on exploring the ideas generated in the previous metadiscourse discussion, which involved concepts like evolution, the food chain, and life cycles. Students worked together to collaboratively create an improved theory explaining what helps a particular species of bird survive.
- April 11th—Connecting ideas across unit: Students looked at KBDeX-generated visualization that depicted shared words that the students were using across the Bird and Salmon units.
- May 2nd—In this session, students viewed a Concept Cloud about salmon reproduction as well as the metadiscourse bar graph in order to reflect on and review the growth in contribution types in their discourse since the first weeks of their inquiry.
- May 9th—In this metadiscourse session, students were shown both the metadiscourse graph

as well as the three different Concept Clouds ("Our Words," "Experts' Words," and "Our Shared Words"). Students discussed why their discourse featured more of one contribution type than another, and also explored possible reasons why there were a number of "expert" terms they had not used in their investigation.

- May 17th—Final treatment session: multiple choice test and discussion.

7.3.4 Dataset

The dataset for the study consists of the following: i) Grade 2, 2012—203 notes across eight views from their "Bird Study" (175 notes, seven views) and "Salmon" (90 notes, one view) units; ii) Grade 2, 2013—258 notes across eight views from their "Bird Study" (117 notes, one view) and "Salmon" (143 notes, one view) units; iii) video of student "KB talks" and metadiscourse sessions, which supplement student notes.

7.3.5 Plan of analysis

The same approach for analyzing data that was utilized in Design Cycle 1 was applied to analyses in this design cycle. This includes evaluation of the growth of contribution repertoire using the "Ways of Contributing" coding scheme, calculating secondary contribution measures such as contributor diversity, richness, and total contributions made, and assessing knowledge advancement using scales for "scientificness" and "epistemic complexity."

7.4 Results

In the section that follows I outline the results of both quantitative analysis as well as qualitative exploration of students' discourse throughout the year.

7.4.1 Did the experimental group or benchmark groups contribute more diversely than their peers the previous year?

Significant effects were found for "Theorizing," $F(2, 40) = 3.48$, $p < .05$, and "Obtaining Information," $F(2, 40) = 4.18$, $p < .05$ (see Figure 54). Post-hoc tests show that Group B contributed significantly more than the 2013 class to "Theorizing" ($p < .05$, Cohens' $d = 2.80$), namely "proposing an explanation" $F(2, 40) = 7.22$, $p < .01$. Moreover, the 2013 class was also outperformed on "Obtaining Information" ($p < .05$, Cohen's $d = 1.66$), namely "introducing a new fact from a source" by both Group A ($p < .05$, Cohen's d = 1.32), and Group B ($p < .01$, Cohen's d = 1.67), respectively (see Figure 55).

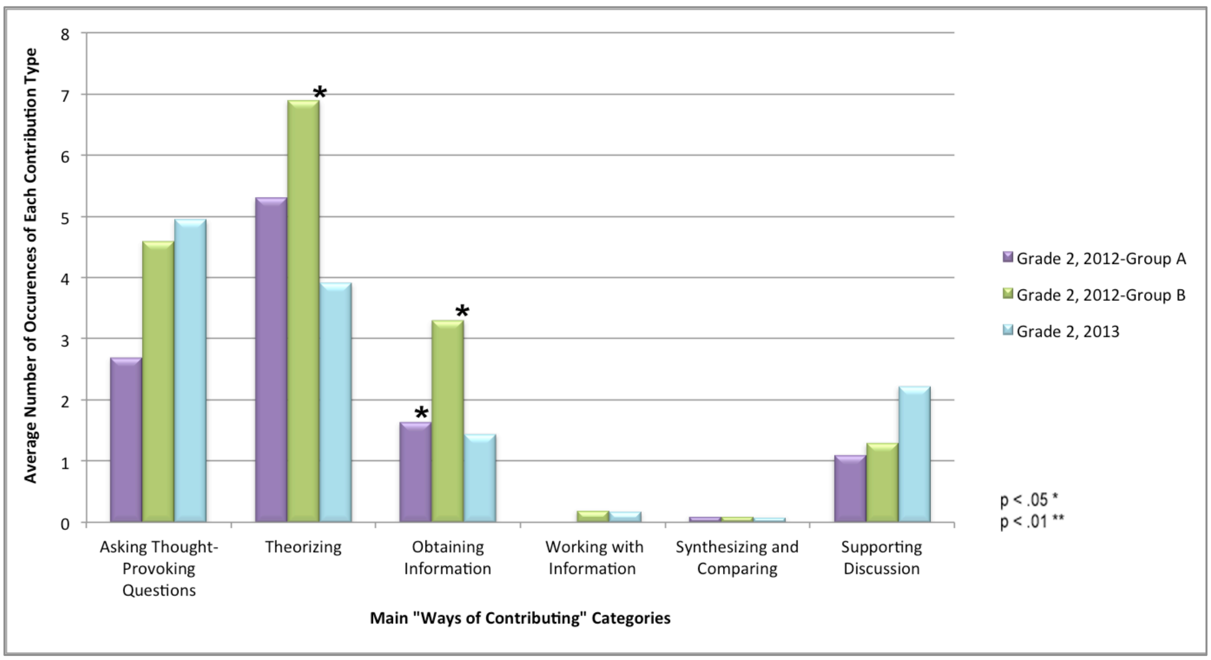

Figure 54. Means (*n*) for main "Ways of Contributing" types in the online discourses of three groups in Grade 2, 2012 and Grade 2, 2013.

No significant differences were found between the 2013 class and either Group A or Group B on any secondary contribution measures (see Figure 56), indicating that, while the 2013 class might not have contributed as frequently to the select contribution types named above, they contributed about as diversely and frequently as the 2012 class. In fact, for all secondary contribution measures except for richness, the 2013 class falls between the performance levels of Group A and Group B. For instance, the average number for total contributions in the 2013 class was 12.8, with the average in Group A and Group B from 2012 was 10.8 and 16.4, respectively. Similarly, the means for contributor diversity on the subcategory level across these groups are 5.6 (2013), 5 (Group A), and 6.4 (Group B).

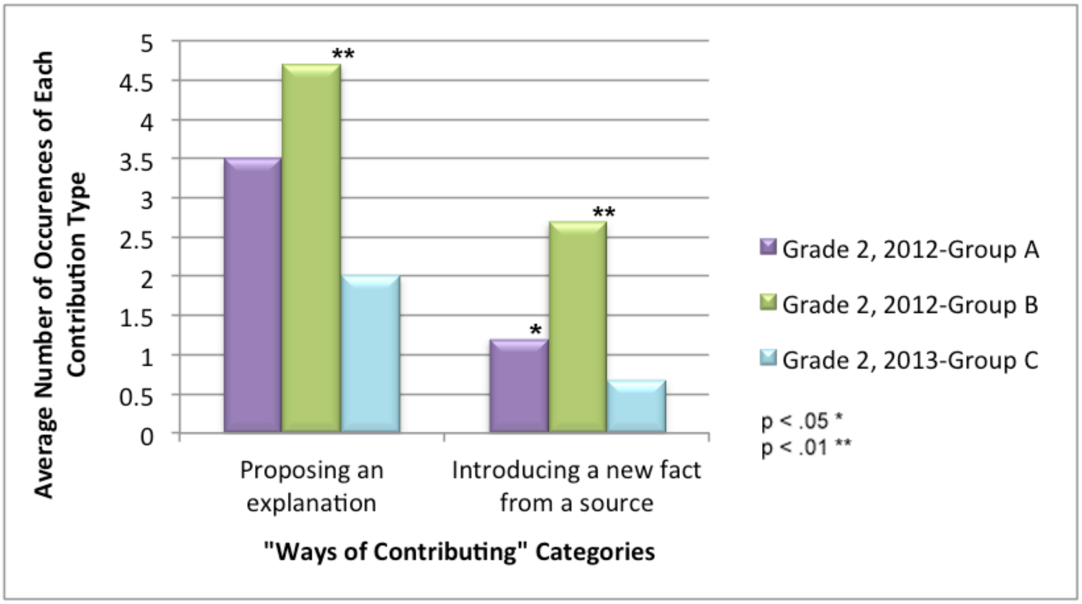

Figure 55. Means (*n*) for "Ways of Contributing" subtypes showing significant differences in the online discourses of three groups in Grade 2, 2012 and Grade 2, 2013.

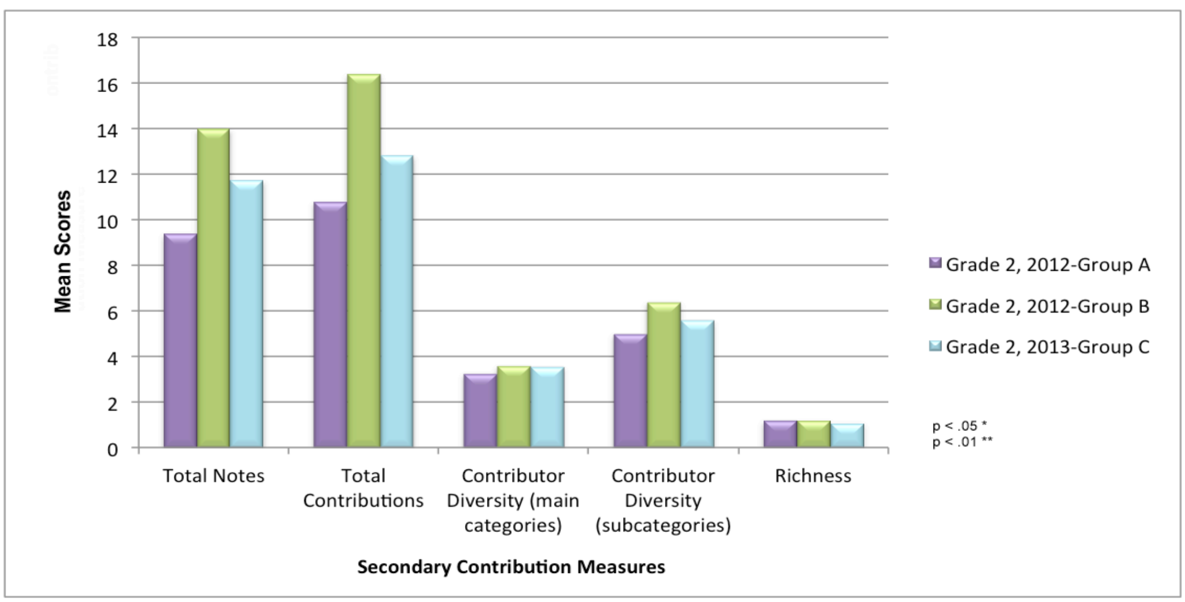

Figure 56. Means (*n*) for secondary contribution measures across three groups, in Grade 2, 2012 and Grade 2, 2013.

7.4.2 Did the experimental group achieve greater knowledge advancement?

There were no significant differences found between groups on either measure for knowledge advancement, including both "scientificness" and "epistemic complexity" (see Figure 57), suggesting both groups were performing on par with respect to both knowledge advancement measures and making significant advances in these areas compared to the 2010 and 2011 benchmark classes. These findings suggest that integrating vocabulary-based and contribution-oriented feedback within repeated metadiscourse sessions can have a positive effect on students' Knowledge Building work.

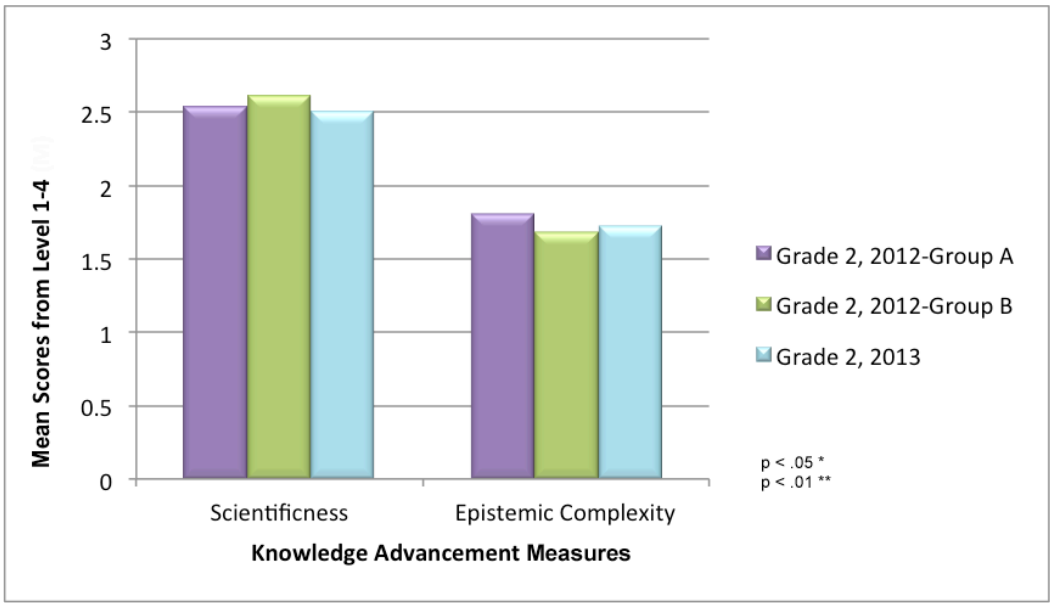

Figure 57. Means for knowledge advancement scores across three groups in Grade 2, 2012 and Grade 2, 2013.

7.4.3 Ways that the Grade 2 students were advancing community knowledge

In this section, I evaluate the extent of students' knowledge advancement related to the "Big Ideas" in the "Understandings Life Systems" stream. Like their peers in previous years, the most popular questions posed by students in the 2013 class also involved questions about how or why birds fly (particularly, how hummingbirds fly), as well as questions about how birds make nests, why there were so many different kinds of birds, and where birds come from. In the proceeding sections, I discuss the students' ideas involving bird's origins and species diversity in particular, which occupied a considerable space in the students' dialogue both on and offline. Before this, however, I will briefly describe two studies that explore young children' biological ideas in order to help create a evaluative framework against which to assess the depth of understanding the Grade 2 students demonstrated in their Knowledge Building discourse.

7.4.4 An evaluative framework for assessing students' evolutionary ideas

Studies by Samarapungavan and Weirs (1997) and Evans (2000) that explore young children's understandings about evolution and adaptation are examined in detail here in order to help to provide an evaluative framework for a qualitative exploration of the discourse of students participating in this thesis research. As previously described, Samarapungavan and Weirs (1997) proposed 4 types of explanatory frameworks that children would likely demonstrate in their ideas about speciation; these frameworks were then adapted by Evans (2000), and can be described as follows: i) Non-Evolutionary—this explanatory framework views species as immutable "natural kinds" that spring "full blown" from seeds or eggs, or that God created fully formed; changes in species only occur as a result of extinction due to inability for said species to survive in its environment; ii) Hybridizationist—this framework predates adaptational theories and includes ideas of cross-breeding between existing species as an explanation for speciation; iii) Micro-Evolutionary—this particular framework assumes that species have basic essences, similar to non-evolutionary ideas, but also allows for small changes to occur within an exemplar species due to environmental change, such as a "dinosaur-tiger" changing into a modern day tiger; iv) Macro-Evolutionary—this represents the most scientifically accurate framework, and posits that new species emerge from pre-existing species over time in an evolutionary process (both

Lamarckian and Darwinian concepts fall under this category).

Within these four major frameworks, a bottom-up approach was used to assess student ideas and divide them into six subcategories corresponding to these four main frameworks. The first three categories—Creationist, Pure Essentialist and Spontaneous Generation frameworks—align with Non-Evolutionary ideas; the fourth, which is titled Dinosaur Essentialist, speaks to Micro-Evolutionary ideas; and finally, the Lamarckian and Neo-Darwinian subcategories correspond to Macro-Evolutionary ideas.

Having outlined a useful framework against which to assess the ideas of the Grade 2 students involved in this study, I move on to exploring their discourse in more depth.

7.4.5 Students advancing knowledge about the "Big Ideas" in evolutionary biology

I begin my qualitative exploration of students' discourse by highlighting the initial question and answer contributions that the Grade 2 students had that correspond most directly to the "Big Ideas" in evolutionary biology. At the beginning of the inquiry unit, students were asked to write down the most pressing question they had about birds, and post these onto the classroom "Wonder Wall." Students were then asked to write initial responses to these questions, which they would then investigate in more detail during the course of the inquiry unit. The initial questions that the students had included: "*I wonder where birds came from,*" "*I wonder why birds are so different,*" and "*I wonder why birds are different from other birds.*" The responses that students offered to these questions before they undertook any inquiry work are as follows: "*I don't know [where birds came from]. Because some birds might have come from somewhere, but this is the thing that I don't know, is how different birds came from. I don't know how an owl could come and a crow could come after. I think they came from different ways, but I don't know how to explain. I'm not sure if they came from a different way or the same way*"; "*Because* *they're different kinds, maybe. They look different because they're different kinds*"; and last, "*Because there are so many different birds in the world. Some can fly. They live in different places. They eat different things. Some are heavy and some are not. And some can be colourful. And some have long tails and some have short tails.*" As these examples suggest, even students as young as seven or eight years old can pose meaningful questions that can serve to frame a deep and sustained inquiry on such ideas as speciation and adaptation. They also contain basic conceptions about how species might transform or why there are a wide variety of species within a single genus. These initial ideas provide a valuable platform from which to begin an inquiry around evolutionary biology, with specific relation to the life systems and biological history of birds.

Near the beginning of the inquiry on birds, a class discussion took place that engaged a phenomenon that is of vital importance to Darwinian evolutionary theory—inter-species variation. As noted earlier, while Samarapungavan and Weirs (1997) found that 8-13 year old students were generally dismissive of small differences within a single species, the Grade 2 students in this study were quite curious about the phenomenon early on in their inquiry work. For instance, while out on a whole-class "nature walk" in which students were observing the birds that were living in and around the schoolyard, one of the children questioned how it was that among a flock of pigeons, only one was white, while the rest were black. The excerpt below details part of the discussion that was initiated by this question:

> *Student A*: They're different colours… some people think that every bird is not the same even though they're the same species, because they have different things that aren't in common because some birds, like humans, get diseases when they're born and sometimes they [birds] get diseases when they're born too. For instance the baby pigeon was born and it couldn't fly for a long, long time and it was kinda like that where other birds got mixed up but they're really the same or a different kind of bird attracted to a different

kind of bird by like, and mixed their colours.

Student B: But every bird always has a disease for its whole life, their feathers have diseases.

Student A: Ya, so if you touch a feather sometimes it has diseases on it.

Student B: Ya and it can be contagious.

Teacher: So you're saying there are different kinds of birds within one species so one species might look very different. And then, there are different kinds of birds…

Student B: If there are different kinds of birds and they mate, that doesn't make a different kind of bird.

Teacher: What makes a different bird?

Student B: If just a different species mates a different species, like a hummingbird marries a pigeon…

Teacher: And then what do you get?

Student B: You get like a half hummingbird and a half pigeon

Teacher: Is it possible for a hummingbird and a pigeon…

Student A: The baby would flap 100 times per second…

Student B: And they would be grey.

Student C: I'm adding onto [Student B's] idea, because I heard in this book that a zebra married a horse, and it was a horse with zebra stripes.

Student B: That is true there is one like that.

Teacher: So you're saying that this can also happen with birds, like it happens with horses and zebras. So species can intermix? So that might be why there are so many different kinds of birds?

Student B: So they can make new birds.

Teacher: So does that answer where do birds come from?

Student B: Ya, they come from one bird… it's…

Student C: I think that they might come from a different family, and maybe it's something like, um, they I don't really know, but like, I don't really know, but it might be like, an animal married another animal that becomes a bird, and then a bird, maybe, ya…

Teacher: So it changes over time? Does anyone know the big word for that?

Student B: Extinction?

Student D: Transformation?

Student B: I think I know why there's no more kinds of birds, because if they make a new bird, if two different species make a new bird, people would want to just hunt it because they didn't make a law to not kill those, and then it would go into extinction…Like the dodo!

In this example, students articulate ideas that encompass a hybridization framework that explains speciation as the spontaneous breeding of two unrelated species. For instance, Student B is careful to make the distinction that breeding among two variants of a single species is not enough to create an entirely new species—for that, two completely different species need to mate. Student C supports this idea by referencing information she found in a book about a Zebra hybrid, an animal that Charles Darwin himself noted in his studies. Ferrari and Chi (1998) found that the notion of hybridization as an explanation of the evolution of species can be found in students much older than the elementary grades, and is even apparent in the ideas of undergraduate science students. It is not difficult to see how examples such as the Zebroid can reinforce popular misconceptions and Lamarckian ideas of genetic inheritance as mechanisms of evolutionary change. The student who responded to the question "where do birds come from" appears to believe a transformation of kind must have occur at some stage in birds' evolutionary history, as she claims at first that birds might have come from "a different family," before referring back to hybridizationist ideas with the comment that "an animal married another animal that becomes a bird." It is interesting to note that the participants in the studies conducted by both Samarapungavan and Weirs and Evans did not demonstrate hybridizationist ideas to any considerable extent. Further work beyond the scope of this study is needed to determine the reasons for the dominance of this particular framework in the Grade 2 discourse, which could include not only an exploration of students' ideas but of parental belief as well (see Evans, 2000 for more on how parental beliefs might play a role in children's emerging understanding of the origins of species).

The discussion about "where birds come from" and "why there are so many different kinds of birds" continued on in students' written contributions. A number of questions probing the issue of the origins and transformation of species emerged on the database as the inquiry progressed, and included the following: "*I need to understand: where birds came from, and why there are so many different kinds of them, and what birds are made of,*" "*I need to understand: what came first people or birds?*" and "*why are birds different colours?*" Students' responded with some preliminary theories to these questions. For instance, in response to the first question, students theorized that, "*there are so many different birds because that's how they survive. And birds need other birds to survive*"; "*they live in a different place and eat different things,*" and "*my theory is birds came from extinction.*" As these examples show, students' ideas related to the question of why there are so many varieties of birds reflect important concepts such as adaptation and interdependence of species to ensure survival, which correspond to macro-evolutionist frameworks. Responses to the question of birds' origins are less advanced, and reflect essentialist or hybridizationist ideas. As seen in this discussion, having a discourse in which students can contemplate both questions in tandem creates a diversity of ideas and also opens up a problem space that calls for theories that can explain both problems of origin and of transformation.

Midway through the inquiry, the questions 'where birds come from' and 'why there are so many different types of birds' were revisited during a group metadiscourse session. The nature of this discussion was quite different from the discussion explored above and represents a significant shift in the children's ideas about how to explain the birds' origins and species variation. The following is an excerpt from this dialogue that reveals a progression in student ideas about speciation, and begins with an attempt at having students' reflect on the written entries they made into the database.

> *Teacher:* So really, this is a three-part note. It looks like it includes I need to understand where birds came from, that's one part, why there are so many different kinds of them, and

what they are made of. What do you think of that note? [Student A]?

Student A: Evolution.

Teacher: What does that mean?

Student A: It means that birds were dinosaurs of a different kind, and then they "evoluted," or um, or, like us.

Student B: We were apes, and then we turned into humans.

Teacher: [Student C], what did you have to say? Was it about evolution?

Student C: Everyone used to be an ape. That everyone's ancestor used to be an ape.

Teacher: Everyone's ancestor? What does that mean?

Student C: It means people from a long time ago, that you don't even know.

Teacher: So what's the difference between something that you used to be and what your ancestor is?

Student D: Because when you were in your mom's stomach, you weren't hairy and "apey"!

Teacher: So that's evolution? That's your definition of evolution. Does anyone else have a definition of evolution?

Student E: The first people on the world were apes. It was ape, human, caveman, and then human.

Student D: No, it was fish, rat, ape, caveman, human.

Student C: No, its cells!

Teacher: Oh my, keep going…

Student D: Cell, ape, caveman, then human.

Teacher: Does anyone have another definition?

Student A: Something that was formed...Okay, something that is formed from something else.

Teacher: So where do birds fit into this? You said they "evoluted." You were talking about how man evolved. How do birds fit in? We talked about cells, we talked about fish…

Student F: They probably formed from something.

Student G: We are living through the time, so birds are probably adding onto something.

Teacher: So how sure are we about this notion of evolution? So pretty much everyone here is saying that humans evolved. So are we pretty sure about this notion of evolution for birds?

Class: Yes! [Nods].

Student H: It just wasn't from a caveman. Because a caveman is a human.

Student I: A caveman is still kind of like apes...but...they didn't talk fully, they kind of talk like apes.

In this example, Student A immediately cites "evolution" as the explanation to the question of bird's origins and the reason for species variations. This response represents an advancement in use of appropriate vocabulary since it is more scientifically accurate than those used earlier in the inquiry such as "transformation" or "extinction." While the student shows some difficulty explaining what the concept means exactly in her own words, her ideas that "birds were dinosaurs of a different kind… that evoluted" represents a conceptual advance over hybridizationist ideas that dominated the earlier conversation and incites a dialogue that emphasizes the importance of change over time to the evolutionary process. The students' spontaneous mapping of the course of human evolution from cell-based forms of life reflects a macro-evolutionary framework in a Lamarckian sense, in that species are seen as "adding onto something" that came before—more specifically, species transformation begins with simple organisms and follows a trajectory that leads to more complex, intelligent forms of life. Students' ideas can also be described as macro-evolutionary in that they reflect the notion that species thus do not have immutable essences but transform over time. In order to ensure students' ideas from group conversation were recorded in the database, the class created a group note which aimed at bringing together the students' ideas about "where birds come from" and "why there are so many different kinds of birds." The note included the following ideas: *"Humans evolved from cells to fish to rodents to apes to cave men to people; evolution means something is formed from something else; Birds come from evolution and they are adding on to the evolution of something else; The cycle of life: two birds had babies, those babies had babies, and those babies had babies, and they changed colours along the way, and now we have lots of birds; Food chain: If there was only 1 kind of bird it would be difficult for it to survive because it would not have much to eat. So, there have to be a lot of different kinds of birds."* The intention for group notes was that they serve as aids to help the class collectively create an improved theory in subsequent a metadiscourse session.

At this point in the discourse, students' ideas did not exhibit Darwinian concepts of evolution, for instance, ideas involving adaptive adaptation and within-species variation. However, their conceptions were fairly advanced when it came to considering static adaptation—the characteristics and abilities an animal possesses that makes it particularly suited to its current habitat. Indeed, students had a strong sense that adapting to a particular environmental niche was important for an animal's survival. Take, for instance, this discussion that followed when the question of "why there are so many different types of birds" re-emerged yet again during another "KB" talk when students' brought up the problem of how there could be one white pigeon in a flock of black pigeons that arose earlier in the unit:

> *Teacher:* The comment was 'how there was only white bird?'
> *Student A:* If it was just one kind of bird. How would they survive if they didn't have other birds to protect them? Like hummingbirds, they build their nests around hawks. Even though they might try to eat them, but they're too fast so the hawks don't bother them. But hawks eat other kinds of birds, so if the hummingbird was the only kind of bird... so... if hawks were the only kind of birds, what would they eat?
> *Teacher:* What do people think about this. There need to be other kinds of birds so that birds can survive.
> *Student B:* Why can't hawks just eat other animals like on the ground... like squirrels
> *Student A:* It's hard to find little tiny ones... they have to eat little things
> *Student C:* What if they ate the corpse of different animals
> *Teacher:* [Student A] and then [Student C].
> *Student A:* 'Cause if the hawks were there and all they would be eating is little things, it wouldn't exactly work, because they're too fast for them they dive from really far away, so it gives the food time to get away. So unless its like a bird in the air. If its mice or rats, it would be hard for them to catch their food. If it's a birds, If it's flying they can just catch them in the air.
> *Teacher:* So it's easier for them to be a predator of a bird than other animals. What do you think about this notion of birds being different. Why would there be different kinds of birds?

Student D: Hawks probably have a bigger appetite so they need to catch a lot and it would be hard for them.

Teacher: This leads to [Student C], you were saying something about corpses?

Student C: If there was only one type of bird in the world... they would probably eat the corpse of another animal.

Teacher: What evidence do you have of this? Can you tell us about it?

Student C: In my backyard I saw a dead squirrel.

Teacher: What bird was eating it?

Student D: A hawk was eating it.

Teacher: [Student E], go ahead.

Student E: hawks eat other birds definitely. I saw a huge seagull dead on the ground, and bones were thrown all over the place, and it was definitely a hawk... or an owl.

Student F: I'm sort of adding onto [Student C]. If there was only one hawk and one bird, the hawk wouldn't survive that long because he only has one bird to eat...[*inaudible*]. So it's kind of like a cycle of food. A food chain.

Student D: I think hawks because they're like... there tons of pigeons in Toronto.

Teacher: So the food source is plentiful. Anyone else?

Student G: The strongest birds. Cause they eat meat. And they drink water and stuff. And they're stronger so they get a longer life.

Teacher: And meat makes them stronger?

Student G: No, not exactly.

Student A: I think humming birds. Because they have the best survival. They're really fast. This one is way too fast for a hawk. And peacocks. Nothing really wants to eat a peacock.

Student H: And more people put out food for them.

Student I: I think maybe pigeons because people feed them bread.

Student H: I think that the last one makes a bit more sense… they have I think that pigeons has the highest chance of survival or the hummingbird because they are getting protected by the hawks and no other birds would like to be next to a hawk…

Teacher: So, the red-tailed hawk is doing really, really, well. Pigeons are doing really, really, well…

Student J: But the red-tailed hawk is really, really rare. And that's why you don't see them?...I think I know why they're there, because they're close to pigeon park.

Teacher: And where are the pigeons in pigeon park?

Class: Everywhere!

Student K: They can be in pigeon park because they love pigeon park because people just throw their garbage on the ground everywhere.
Student H: Pigeons, lots of people like to litter, because if they have bread, leftover bread they just shred it and throw it on the ground, so the pigeons get to eat it all up in pigeon park, because pigeon is mostly where they throw crumbs on the ground. And some people just like to throw it on the ground. And, the red-tailed hawk is high of survival because there is a lot of pigeons in pigeon park.
Teacher: So, somehow or another we just got entered into this whole food chain conversation didn't we?
Student L: I think its called a food chain because, like, a bird needs little to survive, a bird needs a person to survive because a red-tailed hawk does because…If most red-tailed hawks like pigeons and so, the pigeons eat the litter and then the red-tailed hawk eats the pigeon and that's one chain, and then there's another chain, so there's different chains.

As this conversation shows, students had a strong sense that adapting to a particular environmental niche is important for an animal's survival and that species (plant or animal) interdependency is a critical concept that feeds into an animals ability to thrive. The concept of the food chain is dominant in students' discussions of adaptation as a vehicle through which to decide the fitness of different types of species. The idea posed by Student L that "there's different chains" represents quite a profound insight for a student so young, and hints towards the idea of a "food webs" that represents a complex system rather than a linear pathway of feeding relations. Another group note was composed to bring together students' ideas once again, and included the following points: "*What type of bird has the highest chance of survival? Birds need other kinds of birds to survive. For example, hummingbirds need hawks to help protect them. Red-tailed hawks have a high chance of survival because there are a lot of pigeons in the city. Pigeons have the highest chance of survival because there are lots and lots of them. Hummingbirds because they are protected by bigger birds, like hawks.*" As the discourse shows, students were able to recognize that adaptation includes certain behavioural characteristics (red-tailed hawks are strong and predatory), and an ability to take advantage of the environment (hummingbirds build nests close to hawks to be protected, or pigeons live in pigeon park because humans feed them). Students were also able to recognize that there was some larger system binding different species together in various feeding relations, and acknowledged that different species had high chances of survival for different reasons. As this example shows, these young students demonstrate an impressive capacity to talk about and understand aspects of static adaptation within a wider conversation addressing the phenomenon of species variation.

The final discussion excerpt that is explored is derived from a metadiscourse session that took place near the end of the inquiry, and represents an attempt by the class to synthesize available ideas and rise above the current state of community knowledge—a task that presented particular challenges. For example, when reviewing all the theories the class had generated so far, one student commented: "I have a big question about all of those. Hummingbirds are protected by red-tailed hawks and red-tailed hawks eat pigeons and pigeons have a lot of pigeons, so they're all in one big food chain, or they're all related?" Here, this student demonstrates a sense that there is something larger binding the relationships the students are drawing between different bird species. However, when students began to try and draw connections between their theories, the discourse shifted more towards argumentation as the problem became reframed from discussing how these species are related, or what makes different species well-adapted to the same habitat, to debating which bird species had the best chance of survival in general. The notion of a hierarchical food chain became influential in students' discourse at this point. By the end of the session, students had composed the following note to represent an improved theory: "*Our improved theory: We think hawks have the greatest chance at survival because they have practically no predators. They are at the top of the food chain for birds."*

While the ideas in this group note do not necessarily reflect the depth at which students themselves engaged the concepts of adaptation and evolution, they continued to incite questioning and theorizing, as student's continued to interrogate their own ideas and offer new theories as the inquiry continued. Take, for instance, this young girl's question posted during a KB session that took place after the above group note was composed: "*I need to understand: what hawks eat where they live why they are at the top of the food chain if they're the one rarest?*" Students also contributed new theories, such as "*My theory: I think hawks and hummingbirds are the safest birds.*" This culture of continual questioning and idea improvement gave students the opportunity to revise and question their own ideas and push the limits of community understanding. So, while students in this case experienced difficulty achieving a particular knowledge advance, the very effort undertaken to improve or synthesize ideas as a group resulted in further questioning and contribution of new ideas that were "on course" and could help students deepen understanding about important concepts in evolutionary biology as the inquiry progressed.

In sum, the notion that young children can construct naive explanatory frameworks related to speciation is supported by the discourse explored above, in which students exhibit a range of ideas and theories related to evolution and adaptation. Also, unlike findings from previous research (described above) that show young children tend to exhibit non-evolutionary concepts in their responses to questions of species origins and mechanisms of change, the students in this study demonstrated an impressive capacity to articulate ideas that correspond to micro and even macro-evolutionary explanatory frameworks. However, in accordance with previous findings, the Grade 2 students whose ideas reflected evolutionary responses were also more likely to evoke Lamarckian rather than Darwinian mechanisms of change. Indeed, the importance of inter-species variation and the idea of adaptive change appear to be quite challenging for students to grasp or conceive. Though in this case, the students are not dismissive of inter-species variation but simply have a difficult time extending ideas to consider how such differences play a role in species transformation. Nevertheless, the children's discourse demonstrates that Knowledge Building students as young as Grade 2 can successfully improve their knowledge base of the important ideas and concepts in evolutionary biology. Also, the fact that students' ideas showed notable progression on this complex subject matter promising, given the notion that the stronger the knowledge system children possess, the better the position they are in to make conceptual advances within that system (Carey, 1991; diSessa, 1993).

7.4.6 Quiz assessment

As a form of assessment to gage students' understanding of evolutionary ideas at the end of the unit, a multiple-choice quiz was conducted (see Appendix H). The questions were adapted from interview questions utilized in the study by Evans (2000), and targeted species origins and mechanisms of change. In the quiz, two questions mapped onto considerations of species origins; two questions asked students to identify physical characteristics needed to survive in particular environments; and three questions addressed mechanisms of change, particularly how animals might adapt to changes in the physical environment. The quiz also included a small section that addressed questions of environmental stewardship in the context of salmon conservation. Where relevant, the choice of answers for each question that addressed species origins corresponded to the four main explanatory frameworks described earlier. The questions that addressed mechanisms of change included responses that mapped onto intentional/teleo-vitalistic, Lamarckian, or Darwinian explanations.

The test was not formal in the sense that students were not aware of it beforehand and it would not be used to inform any other assessment about an individual students' achievement. The quiz was administered online using an interactive quiz program. The quiz was taken as a class, but each individual student was able to contribute their own answers using their own individual laptops. The teacher monitored the pacing of the quiz so everyone moved at the same speed. Results from each question were made available in real time and were projected on the classroom Smartboard in the form of a bar graph. Short period of discussions followed each question and were facilitated by the bar graph visual that showed an overview of the class responses.

Regarding the two origin questions, students were equally divided between evolutionary (32%) and a non-evolutionary frameworks (32%). Furthermore, 18% of students though the response based on a hybridizationist view was correct, while 16% of students selected the response involving human agency. 2% of students offered no response. Whereas Evans (2000) found that young students tend to hold Creationist or Essentialist views when it comes to explaining species origins, this set of Grade 2 students exhibited sophisticated understanding more reflective of older children between the ages of 11-12. However, a survey of results for the set of questions dealing with the question of how species adapt to environmental changes revealed that 68% of students chose the response that corresponded to non-evolutionary ideas—namely, that species would not be able to survive but would all die out. Furthermore, only 16% of students relied on a Lamarckian/teleo-vitalistic framework, while 11% selected answers that reflected Darwinian ideas, and only 2% of students selecting answers involving human intervention. 3% of students offered no responses. When questioned about their choices, students claimed it was either implausible that a whole species would die out and not be able to withstand major environmental changes (e.g. "You can't expect that all of them died, like he [*gestures to student next to her*] said. Only some of the survived probably but they also went to a new home"), or else that a species could simply develop the physical characteristics needed to survive in a new type of environment (e.g. "I think they all died, because how could they survive? If they had webbed feet they could survive, but how could they? They would probably drown," or "I have swimming on Wednesday and my swimming teacher told me that you need long, put together feet to swim faster, like a flipper, so I don't believe that, so I said the first one [they learned to swim]. It was really hard, but…I don't really think they turned into webbed feet").

This apparent difficulty in understanding how species transform over time highlights a conflict in students' ideas—on the one hand, at multiple points in the group discourse, students' theorized that species do indeed transform over time. However, when asked directly whether species can adapt to environmental change, the majority of students thought they could not. This belief may very well be related to students' understanding of static adaptation. For instance, as described previously, these young students demonstrate an impressive capacity for understanding how particular species are able to survive and thrive in their particular environments. When the fact that successful species are very well-adapted to particular environments is considered next to the fact that species do indeed transform over time—which the majority of students in this group advocated or accepted in general—a space of conflict opens up as students are presented with the challenge of pondering how exactly adaptation occurs and the task of reconciling apparently conflicting facts.

The final question in the quiz offered responses that mapped only onto an Evolutionary framework and included statements that reflect either Darwinian or Lamarckian ideas. Interestingly, although students had difficult understanding how a species could transform to fit its environment, half of the students chose Darwinian ideas as the mechanism that allowed for adaptation on this question. 45% of students chose responses the reflected Lamarckian conceptions—of this total, 18% thought explanations dealing with genetic inheritance were correct, while 27% selected responses that elicited behavioural or teleo-vitalistic ideas. 5% of students did not respond. These results are of interest because they suggest that, while young students have difficulty conceiving of Darwinian concepts, the role of inter-species variation in the process of adaptation appears to make more some sense to them, at least in the context of this activity, than ideas of inheritance or behavioural changes, which comprise the basis of the most common misconceptions in evolutionary biology. This raises the possibility that even Grade 2 students could productively engage with Darwinian concepts of if they are introduced in the context of authentic inquiry; moreover, as I will discuss further in a subsequent section of this chapter, this finding suggests that similar informal assessments can be used as a way to introduce counter-intuitive ideas to students to help them advance their own ideas to a greater extent as they engage in collaboratively Knowledge Building.

7.5 Could young students productively engage in metadiscourse?

As in the previous design cycle, field notes helped to provide important contextual data to shed light on the ways students participated in metadiscourse sessions and how they interacted with the formative feedback that they were shown as part of the design interventions. The following discussion is organized into three main components, including responding to feedback, discussing scaffolds, and making diverse contributions, as elaborated below:

i.) *Responding to feedback:* Students in the 2013 class responded in positively to both forms of feedback visuals they were shown during their inquiry. For instance, the metadiscourse bar graph was read and interpreted easily by the students in general. Also, the Concept Clouds compelled the same kind of physical and gestural interaction as they did with the 2012 class, with students frequently walking up to the Smartboard screen to touch or measure the size of the words displayed. Students also were actively making use of the information provided by the Concept Clouds both in their group discussions and in their online discourse. For example, during the final metadiscourse session on salmon, the class viewed the “Experts’ Words” Concept Cloud and discussed some of the terms that were present in the visualization but which were not part of their own discourse, such as "migration." Whereas students did in fact discuss the life cycle of salmon and their instinct to return to the rivers in which they were born, they never used the specific term "migration" in their conversation. When the students were asked why the term was featured in the Concept Cloud, students were able to easily provide reasons and to explain the term itself; take, for instance, this young girl's description: "This is what they do, okay, so the little baby eggs hatch and when they become like five or something they go somewhere else and they go somewhere else and then when they become parents they go back to where they were born." As this students' response illustrates, lack of the term in the discourse does not necessarily indicate lack of knowledge or awareness. Thus, viewing the "Expert Words" cloud in the context of students' own inquiry provides a way of explicitly linking the appropriate scientific vocabulary with students' existing ideas.

It also provides a means for students to begin deepening their understanding of these new terms. For instance, in the same discussion engaging the term "migration," one student began reading other words featured on the "Experts' Words" cloud out loud: "temperature or salt water or warm water or life…" When questioned, this student explained that she was picking out all the words that she thought related to the word "migration." Thus, students were actively making connections between words that drew off their existing knowledge and helped to give meaning to new and hitherto unused terminology. Moreover, after this particular discussion, two separate notes appeared in the database that used the term "migration" explicitly: "*why do salmon migrate?*" and "*why do salmon migrate to other places in the world?*" Students did not have time remaining in the unit to address these questions, however their appearance in the discourse represented evidence of the efficacy of the Concept Clouds to students' inquiry.

ii.) *Discussing scaffolds:* In this study iteration, a new scaffold was introduced that focused on idea improvement. The scaffold, "Our improved theory," was new to the students, as they had only worked with three scaffolds in the first grade (e.g. “My theory,” “I need to understand,” and “Important information + source”). The new scaffold was introduced during a metadiscourse session that took place midway through the first unit of study on birds, once the students had had enough time to begin their inquiry and pose questions, generate ideas, and participate in activities like nature walks, and so on. The following example illustrates students’ ideas about what “Our improved theory” means:

> *Student A:* Because… you know how you make a theory, for example, I make a theory why it’s… I’m adding on to somebody who said “how do birds die”, for example… and I say they die because somebody shoots them and somebody says they die because they… like sometimes hit posts and those stuff, and more of that… and an improved theory is when everyone kind of combines all of the theories together and makes like a better theory that makes more sense…
> *Teacher:* What do you think? Would that be an improved idea? Improved theory? Or is that just adding to our other theories? What does improved mean?
> *Student B:* Better
> *Student C:* Better! Ya like when they’re opening up a place... they’re like “the new and improved car!”
> *Student D:* Because if something just says, how do birds fly... how do they…[*inaudible*]. How do they fly?
> *Teacher:* Ahh… so something that’s improved has more detail?
> *Student D:* Or its better.

As this example shows, students found the scaffold understandable and accessible. Student A provides the most elaborate response to what an improved theory means, offering an explanation that actually evokes the concept of explanatory coherence when he suggests that an improved theory is one that synthesizes available theories and “makes more sense.” The Grade 2 students’ response to this scaffold helped to confirm that the scaffold would be of use to the students during their inquiry. In the end, this scaffold was used only once as a group, and twice by a particularly precocious student. The group attempt to use this scaffold is discussed in detail in Section 7.4.5. The individual student tended to use the scaffold to insist on the truth-value of a certain fact that had incited a considerable amount of dialogue within the community. For instance, the student made contributions using this scaffold to the group discussion about salmon behaviour, particularly the tendency for the salmon to hide behind rocks and stay in shadowy areas of the tank. At the point when the class had generated a fair number of contributions about these points of interest, this student included the notes: "*Our improved theory: they're good hiders";* "*Our improved theory: they like the dark, because they're scared.*" While these examples do not reflect increasingly coherent ideas, the student uses the scaffold to make contributions that highlight what he believes are important points in the group discourse. While this example of scaffold use is an interesting one, it is important to the objectives of this research that improved theories reflect the ideas of the whole community and represent the creation of increasingly coherent explanations. Integrating regular discussion about what makes an 'improved theory' can help students develop an deeper understanding of the concept and could encourage more students to think about this very important contribution type, even in the primary grades.

iii.) *Making diverse contributions:* Like the previous year, the importance of each kind of scaffold was repeatedly made explicit to students, namely those contribution types that are difficult for young students to make without extra support, including "Obtaining information" and "Working with information." With respect to "Obtaining Information," students in the 2013 class engaged in a variety of contribution types that fall under this category, such as reporting important facts, communicating observations from experiments and activities, and including citations of sources where information was found. Take, for instance, this example of student's response to the question posed in the database asking "why birds fly": "*Important information + source: to protect them from predators. My source is from my Nature Notebook. I saw a flock of* *pigeons flying away from a red- tailed hawk!*" Here, the student not only recorded an important empirical observation he made, but uses this observation as a source of authoritative information on which he bases a new theory. Other students make similar types of contributions based on observations made during the dissection of owl pellets: "*Important information + source: I think my owl ate a rodent because almost all of the bones came from a rodent"; "Important information + source: owls eat lots of things including things NOT in our owl pellets like weasels, for example, they were not in our owl pellets."* Helping students recognize the value of these types of contributions, and encouraging them to contribute to the dialogue in these ways, are important for helping them develop competencies important to the process of scientific inquiry, and for raising the level of their collective discourse.

7.6 Lessons Learned from Design Cycle 2

A number of lessons emerged from this design iteration that both reaffirmed some successes achieved in the first iteration and presented new areas of improvement that could inform future work. In the following section I comment briefly on the areas of strength in the study design as well as those elements that could be improved.

7.6.1 Lesson 1: Productive design components.

Similar to Design Cycle 1, the use of the formative feedback, including the Concept Clouds and the metadiscourse bar graph, was found to be productive for both helping students to expand their contribution repertories and for advancing group knowledge. Also, the metadiscourse sessions proved invaluable for helping students reflect on their ideas and gain a broader perspective of their inquiry. The positive effects these forms of embedded assessments, both technological and pedagogical, was evident in both study iterations, and support the assertion that these designs reflect examples of productive new formative assessments to support Knowledge Building work.

Moreover, the integration of the “Our improved theory” scaffold was regarded as a success in the ways it influenced group discourse and opened up space for discussing complex ideas. As opposed to the scaffolds targeting “Obtaining information” and “Working with Information” that were tested out in the first iteration, the “Our improved theory” scaffold was useful for facilitating group dialogue aimed at synthesizing available ideas and for inciting conversation that helped to deepen inquiry around the challenging problems of understanding that emerged in students’ discourse.

Finally, the new assessment activities that were conducted at the start and end of the two inquiry units were successful in a number of ways. First, the initial “I Wonder” reflections gave a useful overview of the interests the students had when it came to studying birds. As for the quiz that was taken at the end of both units, the students were extremely engaged in the activity as well as the discussion that took place during the course of the test. Students found the questions difficult, but not inaccessible. Each question invited a number of responses from students who were very enthusiastic to share their ideas and justify their choices. While the “I Wonder” activity and the quiz proved successful elements of the study design, ways in which to improve their function and value in the context of a Knowledge Building inquiry unit is discussed in the following section.

7.6.2 Lesson 2: Design components that can be improved

There were a number of aspects of the study design that would benefit from modifications if they were to be implemented in a classroom in future work. The first of these modifications would be dedicating more time in the Knowledge Building study to discussing the idea of “Our improved theory” with students. As described earlier, even students as young as the second grade can engage in a fruitful conversation about what makes one theory better than another theory. Helping students develop ever-deeper understandings of the concept of an ‘improved theory’ as that which represents an increasingly coherent explanation is a plausible endeavour and one that would surely have a beneficial effect on students’ explanation-seeking discourse. Repeated discussions about the notion of an ‘improved theory’ can also help students to practice applying the concept to their own ideas. Oftentimes, the diversity of ideas and the problems that students bring into the discourse make for dialogue that is quite complex and that presents considerable challenges to students when they collectively take on the effort to evaluate and synthesize their own ideas. Also, achieving theory improvement is not always possible in every explicit attempt. Thus, making students aware that setbacks are part of the process of creating new knowledge, while also encouraging them to continually strive to improve existing theories is critical for helping students to develop an understanding of the nature of explanation-seeking discourse and for the processes involved in creating new knowledge.

Another modification I would recommend for the study design involves the “I Wonder” and final quiz assessments. First, the practice of having every student pose an initial question and tentative response, as the “I Wonder” activity calls for, is a productive way to begin an inquiry unit; however, it would also be beneficial for research purposes to pair this activity with a first implementation of the quiz in order to embed a pre-post test element to the study design. This may also help to emphasize the knowledge gaps evident in the group, giving the teacher and/or researcher a better sense of where students are the most “knowledge poor” or where they might exhibit greater understanding. Also, the end-of-unit quiz in this study was useful in that it helped to reveal where students experienced conflicts in understanding; it was also helpful in exposing students to sophisticated ideas that they were not able to engage on their own. Adapting such an activity to take on more of a formative quality—perhaps implementing a similar quiz more towards the middle of the inquiry than at the end, or repeatedly over the course of the unit—might be beneficial for helping students to work though particularly tricky misconceptions.

7.7 Chapter Summary

This chapter described Design Cycle 2 of the thesis research, which aimed to substantiate positive findings from Design Cycle 1, and show further support for new formative assessments designed to enhance the explanation-seeking discourse of primary aged students. The chapter began with an overview of the changes to the study design that were implemented in light of the lessons learned from the first study iteration. This discussion was followed by short descriptions of two new cognitive and performance-based assessment activities that were integrated at the beginning and end of the inquiry unit. The participants and dataset for Design Cycle 2 were then outlined, followed by an overview of the methodology adopted for the study. A summary of results was then detailed, beginning first with a report of the results of quantitative data analysis, and moving on to address more qualitative aspects of the students' discourse that served to augment quantitative results.

In terms of quantitative tests, results from one-way ANOVA comparisons showed that Group B of the 2012 class contributed significantly more than the 2013 class to "Theorizing," namely "proposing an explanation." Both Group A and B from 2012 outperformed the 2013 class on "Obtaining Information," specifically "introducing a new fact from a source." However, no significant differences were found between the 2013 class and either Group A or Group B from 2012 on any secondary contribution measures. Furthermore, no significant differences were found on knowledge advancement scores between the 2012 and 2013 students. Overall, both 2012 and 2013 classes made significant advances in knowledge advancement compared to the two Grade 2 benchmark classes, 2010 and 2011.

A more qualitative look at student discourse both off and online show that Knowledge Building students as young as Grade 2 can successfully improve their knowledge of important ideas and concepts in evolutionary biology. These results are of interest because they suggest that, while young students have difficulty conceiving of Darwinian concepts (such as inter-species variation, or adaption, etc.), even Grade 2 students could productively engage with these challenging ideas if they are introduced in the context of authentic inquiry. This chapter also included detailed comments on how students interacted with the feedback, the types of contributions they made in targeted areas, and the ways they contributed to metadiscourse discussions.

Finally, the chapter concluded with a consideration of the lessons learned from Design Cycle 2, including recommendations for improvements that could inform potential future work building off this research.

CHAPTER EIGHT: GENERAL DISCUSSION

8.1 Chapter Overview

This thesis describes a research project that included four distinct studies conducted over three phases. The first study conducted in Phase I provided baseline data that informed the subsequent classroom experiments. The following two studies, which were completed in Phase II, report preliminary and secondary data analysis corresponding to treatments implemented in Design Cycle 1. The fourth and final study, conducted in Phase III, reports the enactment and results of work done in Design Cycle 2. All studies explore the ways in which elementary school students contribute to collaborative explanation-seeking discourse in science, and involve work produced over full-length (four months) Knowledge Building units. While the first study in Phase I examined only one complete inquiry unit, all subsequent studies in Phases II and III examined work generated over a full year, or two full-length inquiry units (eight months). The project was a collaborative effort, involving the participation of one teacher, a research aide, a developer, and myself. The outcome of the project was the creation of feedback visuals to bootstrap young children's Knowledge Building discourse and a case-study example that describes technological tools and pedagogical strategies designed to help primary level students expand their contribution repertoire and advance community knowledge in science.

The subsequent sections of this chapter discuss the studies' results in relation to the three main research questions posed in Chapter 1. It also includes commentary on some of the wider implications of the research findings to the initiative of advancing a Knowledge Building approach in more classrooms. I conclude by offering some thoughts on how this research contributes to the Knowledge Building research in general.

8.2 Addressing Research Questions

The series of studies described in this thesis were designed to explore three overarching research questions, as presented in Chapter 1. Here, I reflect on the extent to which the research conducted addressed each question and consider the broader implications of study results to both classroom practice and to ongoing Knowledge Building research.

Question 1: How do young students contribute to collaborative explanation-seeking discourse in their naturally occurring knowledge building work? Are there any valuable ways of contributing that are rare or absent from student discourse, and can thus serve as targets for design work?

Chapter 1 provides an overview of the ways elementary school students contribute to Knowledge Building discourse in their naturally occurring work. A trend was evident amongst the younger elementary grades, with children from Grades 1-4 showing considerable capacity to pose meaningful questions, generate a diversity of theories, and offer opinions and social mediation in their discussion. It was only the older students in Grade 5/6 that showed a different pattern in their contribution repertoire, with an increasing amount of fact-based questions and authoritative information emerging in their discourse. However, a number of important contribution types that were scarce or unseen in students' discourse were common across all grades inclusively—these included contribution types that required students to work sophisticatedly with information or to synthesize available ideas and "rise-above" existing conceptualizations. These moves represent particularly challenging ways of contributing that would serve as targets for future design work and would inform the design of assessment tools that support different aspects of explanation-seeking discourse.

In this study, formative feedback tools that offered students a "bird's eye" perspective on the contribution makeup and the semantic field of their discourse were tested. These feedback forms included the Metadiscourse Tool (Phase II and III), Word Clouds (Phase I), Concept

Clouds (Phase II and III) and verbal scaffolds (Phase II and III). Explicit attention was focused on boosting students' engagement with contribution moves corresponding to "Obtaining Information" (Phases II and III), "Working with Information" (Phase II) and "Synthesizing and Comparing"—namely, "improving an explanation" (Phase III). These contribution categories represented the least frequently occurring discourse types in Grades 1-4 and were thus appropriate to target for our subsequent design experiments.

It should be noted here that the "Ways of Contributing" scheme that was utilized to map and identify the contribution types evident in elementary students' explanation–seeking discourse is not exhaustive and does not demonstrate all possible roles important to knowledge creation; rather, it represents a broad number of contribution types critical to explanation-seeking dialogue that can serve as a basis for a more detailed and coherent model. For instance, current work investigating the capacity of young students to engage in "promisingness judgments" represents a vital aspect of Knowledge Building work that remains unaddressed in this inventory (see Chen, Resendes, Chuy, Tarchi, Scardamalia & Bereiter, 2011). Similarly, new advancements in technologies for Knowledge Building environments might include more sophisticated drawing tools or methods of annotating objects imported from a variety of sources. Thus, the ways in which "visual thinking" processes (e.g. Ware, 2008) play role in students' Knowledge Building discourse, including both the capacity to create images, as well as those involved in deciphering and interpreting images, could be interrogated in more depth. However, the existing scheme is a valuable resource as it covers a wide range of contribution types that one can expect to encounter in elementary-aged students' explanation-seeking discourse, as well as those that ought to be encouraged in the classroom to help young students develop their capacities for constructing increasingly coherent explanations.

Returning to consider implications of results emerging from work in Phase I, findings also revealed that very young students are able to contribute in certain ways with comparable frequency and diversity as older students, given that other environmental factors are conducive to authentic inquiry, such as sustained and frequent engagement in shared discourse both online and offline. For instance, the Grade 1, 2010 class made just as many contributions as students in the junior and immediate years (Grades 4-6), and outperformed their primary peers on various contribution types, such as "asking an explanatory questions," "supporting an explanation," or "seeking an alternative explanation." Such findings support the idea that, just as immersing oneself in a new culture can facilitate learning a new language, the deeper and more immersed students are in a dynamic knowledge creating culture, the more they will build the capacity to create new knowledge and improve their ideas. Working with primary aged students allowed us to explore this claim in practice and enabled us to measure the performance of experimental students against students up to four years their senior who had not been exposed to any similar design interventions; this was important for helping us to investigate the extent to which embedding new components within the existing culture of inquiry in the classroom, in the form of contribution and content-oriented feedback, as well as metadiscourse, could raise the level of student discourse.

Question 2: How can the design of new feedback tools help students to expand their ways of contributing?

Exposing students to feedback visuals embedded in episodes of reflective discussion was found to have a significant impact on the growth and diversity of their contribution repertoire. First, all students that engaged in design interventions demonstrated increased performance on both total amount of contributions made and diversity of contributions, compared to students at the same grade level who did not participate in interventions. These findings allow us to state with some confidence that the metadiscourse bar graph, the Word Clouds, and the metadiscourse sessions had a synergistic effect that led to increased motivation to contribute a greater amount of ideas to written discourse. With respect to enhanced performance on targeted contribution types, experimental Group B in Design Cycle 1 showed significant increases in these contribution moves “Obtaining Information,” namely “reporting experimental results,” and “introducing a new fact from a source” as well as “proposing an explanation.” The latter contribution move was not targeted but occurred as a welcome unexpected outcome. Moreover, the students in Design Cycle 2 showed no significant difference to students in Group B, 2012 in regards to engagement with “reporting experimental results.” This indicates that the 2013 students were still engaging with this important subcategory with more frequency than their peers in the 2011 or 2010 classes. Thus, in both design cycles, students notably increased their engagement with targeted contribution types in comparison with students who did not participate in the design interventions.

However, that the students in Design Cycle 2 did not outdo those in Design Cycle 1 in regards to select contribution measures was unexpected, and could be due in part to two main factors. First, issues with the technology had a considerable impact on the time the 2013 class had to contribute ideas to the online discourse. For example, the groups in the 2012 class engaged in a total of 22 sessions on Knowledge Forum that lasted approximately 30 minutes each, while the 2013 class participated in only 18 Knowledge Forum sessions that ran roughly between 15-30 minutes. Lost time online was due to either problems connecting to the network or to software issues.

Furthermore, unlike the 2012 class, the 2013 students spent time writing notes as a group, and thus made contributions that could not be quantitatively assessed as part of the study (since analysis only considered notes authored by individual students). The process of writing group notes was an important part of the way the 2013 class engaged with the new scaffold “Our improved theory." For instance, due to the lack of engagement with "Working with Information," which was a targeted contribution type in Design Cycle 1, it was decided that it would more fruitful to focus on "improving an explanation" in Design Cycle 2, and to have students discuss what this discourse means and why it is important to their Knowledge Building work. This approach was found to be successful and conducive to lively discussion amongst the Grade 2 students. Students in the 2013 class did make slightly more "improving an explanation" contributions compared to the 2012 students, with this discourse move occupying 3.77% of their total discourse, compared to 3.05% and 3.36% from Group A and Group B, respectively. While this difference is slight and not statistically significant, any increase in theory improvement is important to acknowledge and it reflects a productive and progressing dialogue. Furthermore, comparisons with respect to explanation improvement were difficult to measure because a number of "improving an explanation" online contributions made by the 2013 class reflected group efforts. Thus, as stated, these entries could not be included in the dataset for analysis.

This issue highlights one of the main challenges for assessing aspects of collaborative Knowledge Building work that cannot be attributed definitively to one individual or another but that represent community contributions. What can be taken from this example, however, is the positive affect such collective efforts can have on students' individual work (see Chuy, Zhang, Resendes, Scardamalia, & Bereiter, 2011). This effect is most clearly seen in improvement of mean scores for knowledge advancement measures, which is described in more detail below.

Question 3: To what extent does expanding students' contribution repertoire help them to advance community knowledge?

In both Design Cycle 1 and 2, all experimental groups demonstrated significantly higher knowledge advancement scores, including both "scientificness" and "epistemic complexity," than their peers at the same grade level who did not engage in any design interventions. In fact, when comparing the "scientificness" scores of Group A and Group B from Design Cycle 1 against data from the five other elementary classes derived for the first baseline study in 2010, the experimental students outperformed both the Grade 1, Grade 2 and Grade 3 students on this measure and showed no significant difference with the Grades 4 or 5/6 students. Thus, in Design Cycle 1, the enhancement of students' contribution repertoire, evident in their increased engagement with "proposing an explanation," and "Obtaining Information"—namely "introducing a new fact from a source" and "reporting experimental results"—was manifest in particularly high "scientificness" scores as compared to both two sets of earlier Grade 2 classes (2010, 2011) as well as other student groups from Grades 1-5/6 (2010). Also, the students from Design Cycle 1 and 2 performed significantly better in terms of "scientificness" and "epistemic complexity" of notes as compared to their peers in the previous year (2011).

As noted earlier, students in Design Cycle 2 demonstrated a lesser number of significant differences with respect to engagement with particular contribution types. For example, they showed statistically significant gains only in the area of "reporting experimental results" as compared to students in benchmark classes that did not participate in design interventions. However, students in Design Cycle 2 also demonstrated notable gains with respect to knowledge advancement measures, as their discourse showed no significant differences from that of the dialogue in Design Cycle 1 in regards to both "scientificness" and "epistemic complexity." This could be explained partly as an effect of the group metadiscourse sessions that focused on "improving an explanation" as a critical move in explanation-seeking discourse (which, as mentioned, resulted in the composition of group notes that were not subject to quantitative analysis like the notes of individual students). These findings support the claim made in the thesis that engaging students in repeated metadiscourse discussions that include exposing them to contribution-oriented visualizations like the metadiscourse bar graph, as well as vocabulary-based feedback such as the Concept Clouds, can have a significant impact on knowledge advancement of students and can have an overall positive effect on their Knowledge Building work.

8.3 Implications for Knowledge Building research

As the findings from this research show, getting students off to an early start in Knowledge Building is both feasible and conducive for helping them to develop and practice the competencies involved in the complex processes of creating new knowledge. New technological tools that can serve as useful forms of formative assessments, such as the Metadiscourse Tool and the Concept Clouds, represent simple and accessible designs that teachers and students can utilize to enhance collective discussions and to raise the level of their discourse, even in the primary years. Indeed, in the studies described, these basic visualizations engendered lively discussions around questions that could be difficult to probe without the visual support they provided. An important dimension of power in these forms of feedback lies in their ability to make explicit otherwise "hidden" aspects of the discourse and render them in a comprehensible way, and therefore to engender new types of questions that open up space for taking about the discourse itself. For example, the visuals can help focus students' attention not only on the presence or absence of particular contributions types in their discourse, but could also help students develop an understanding that there are more or less useful times for making certain types contributions over others, depending on the state of the particular inquiry. However, based on this research, it is recommended that group discussion be part and parcel of student interaction and experience with feedback tools such as the Metadiscourse Tool, Concept Clouds, or Word Networks, especially in the primary years.

Indeed, in both Design Cycles, the episodes of reflective discussion in which these feedback visualizations were shown were imperative for their productive integration into the existing inquiry. Metadiscourse facilitated by these feedback visuals also repeatedly compelled a high level of student engagement and written contributions—an unanticipated but certainly welcome outcome. This result supports existing findings that show that formative assessments that are adaptive and embedded in authentic contexts can help positively influence different dimensions of group behaviour, including increased participation in the dialogue as well as greater performance on both qualitative and quantitative measures of achievement (Zumbach, Hillers, & Reimann, 2004). These findings also suggest that, at least for primary-level grades, pedagogy must intersect with technology in order for students to make the most gains. As the teacher in this project described, the tactic of embedding metadiscourse sessions concurrent with reflection on automated feedback throughout a Knowledge Building inquiry represented a strategy that did not feel like an "add-on" to existing practice, but could be achieved in large part by a commitment to taking the time out to focus specifically on reflection and group evaluation of discourse. Moreover, using automated feedback as a way of enhancing group inquiry and discussion was taken up by the students as they worked individually on Knowledge Forum. For instance, students frequently began viewing the metadiscourse graph as they were writing on their own computers; they also had extra incentive to use scaffolds when composing notes because scaffolding activity would be reflected in the feedback visuals. Moreover, students would often run back and forth from their computers to the Smartboard screen where visualizations were projected. For instance, on a number of occasions, students approached projected Concept Clouds to measure relative word sizes with their fingers, or track specific terms that they then looked up in classroom books and resources. These sorts of behaviours and interactions, which emerged spontaneously from the students themselves, reflected an authentic investment and enthusiasm on behalf of students to engage with these tools and apply them in their Knowledge Building work.

8.4 Conclusions

This research explored the extent to which pedagogical and technological innovations can enhance students' ways of contributing to explanation-seeking discourse, and whether expanding students' contribution repertories can help them advance community knowledge as a whole. The research was conducted in three main phases. The first phase investigated the ways elementary school students contribute to their naturally occurring Knowledge Building discourse in order to provide baseline data for subsequent design experiments. The following two phases corresponded to two design iterations that each tested different types of formative feedback developed to encourage contribution diversity and raise the level of student discourse. All phases involved work in elementary level science.

This study contributed to Knowledge Building research in three ways. First, at the onset of this research, the "Ways of Contributing" inventory had not yet been used to catalogue and describe the contribution patterns of elementary students beyond the fourth grade. During the course of the work involved in Phase I, I refined the scheme to include a number of additional contribution types and used it to assess and map the contribution repertoire of students from Grade 1-6. Both the refined inventory itself as well as the baseline data that was produced in Phase I can be taken up and used in other work exploring important dynamics in Knowledge Building discourse. Second, work in Phase II and Phase II, which correspond to Design Cycle I and Design Cycle 2, resulted in the production of usable artifacts tested and shown to be conducive for helping primary level students diversify contributor repertories and raise the level of their collective discourse. These are, namely, the metadiscourse graph generated by the Metadiscourse Tool, and the Concept Clouds (which include variants such as KBDex-generated

Word Networks). These tools have also been shown to be accessible to both students and teachers since they do not require special expertise on behalf of either party to use or interpret. Third, work involving the Grade 2 classes in both Design Cycles 1 and 2 represent valuable case studies that can be used as anecdotal descriptors of how new assessments can be fruitfully integrated into Knowledge Building inquiries, and can work to build or enhance a knowledge creating culture in the classroom. Moreover, these case studies offer empirical evidence in support of "early primary level collaborative inquiry" (EPCI), which represents a current initiative in the Ontario school system (see Ontario Ministry of Education's "Collaborative Inquiry," 2013). The story of how the Grade 2 inquiries unfolded can be useful as a professional development resource for teachers wishing to introduce an authentic collaborative inquiry approach in their own classroom, or to improve their own existing practice.

In sum, this research has shown that formative assessments designed to enhance fundamental dimensions of explanation-seeking discourse can be successfully integrated within a Knowledge Building inquiry at the primary grade level. Students can both productively engage in metadiscourse as well as interpret, respond to and benefit from exposure to feedback that gives them a meta-perspective about their own dialogue. Engaging students in evaluating and assessing their own discourse can both expand the ways they contribute to group discourse but can also help them move their Knowledge Building work forward. The pedagogical strategies and technology tools described in this research can help, it is hoped, to provide a means to scale up a Knowledge Building approach in classrooms on a broad scale, beginning with the very youngest students.

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APPENDIX A—Dr. Eric Jackman Institute for Child Study School Information and Admissions Policies

The following information can be found on the Dr. Eric Jackman Institute for Child Study website (http://www.oise.utoronto.ca/ics/index.html). The excerpts below are taken from the website's "About" and "Admissions" pages specifically.

- "Since its inception in 1925, the Dr. Eric Jackman Institute of Child Study Laboratory School has been a place where children grow mentally, physically, and socially. Within our classrooms, children are challenged to think independently, to use their natural curiosity to critically investigate the social and natural world, and to gain the skills to communicate with others, becoming engaged citizens. Children at the Laboratory School learn to love learning.

  The Laboratory School is a Nursery School to Grade Six elementary school in downtown Toronto. It is part of the Ontario Institute for Studies in Education (OISE) at the University of Toronto and has a threefold mandate: teacher education, research, and exemplary education for the 200 children who attend the school. A satellite Jackman ICS classroom at the Holland Bloorview Kids Rehabilitation School provides an Integrated Junior and Senior Kindergarten Program (IKP) for children with and without special needs."

- "Jackman ICS is committed to diversity in all forms. Three principles underlie ongoing efforts to build a unique learning community and create diverse, gender-balanced, equitable classrooms with broad-based populations representing cultural, economic, and social diversity: *Jackman ICS aims to represent Toronto's diversity, including its aboriginal and multi-ethnic dimensions. Jackman ICS strives for economic diversity by providing limited needs-based financial support. Jackman ICS classrooms are gender-balanced, with 10 girls and 10 boys entering in Nursery School."*

  Preference will be given to siblings of currently enroled children, candidates who have completed the Jackman ICS Bloorview Integrated Kindergarten JK/SK Program, and children of Jackman ICS employees. There is no preferred status for children of the University of Toronto employees beyond Jackman ICS, or for children of Laboratory School alumni. The Admissions Committee, chaired by the Principal, reviews the admissions policy annually."

APPENDIX B—Teach and Internet Consent Forms

Informed Consent Letter – Teachers and Interns

Dear <name of teacher or intern>,

I am the Director of the Institute for Knowledge Innovation and Technology at the Ontario Institute for Studies in Education of the University of Toronto (OISE). Since 1986, Dr. Carl Bereiter and I have led a research team at OISE that is developing new instructional materials and technology-based approaches to foster knowledge building and innovation in education.

As part of our current research funded by Social Sciences and Humanities Research Council, we are working to explore how students engaged in collaborative knowledge building develop distinctive contributor roles or styles, and how these roles contribute to a group's success in knowledge advancement. The goal of this research is to develop improved teaching practices that will raise the level of students' explanations and arguments in science and history. As a teacher interested in engaging a knowledge-building approach to history, we invite you to participate in this research project.

Your participation would involve the following:

1) Designing and implementing activities in collaboration with researchers to foster explanation-seeking dialogue in students.
2) Participating in development of research tools in order to adapt them to the particular purposes of this research
3) Helping researchers to analyze classroom discussions, and the entries that you and your students make into Knowledge Forum (the knowledge building software currently used in your class).
4) You may be asked to be videotaped while you work with students. Participation in the videotaping is strictly optional.

If you agree to participate in this research study, it is possible that short, videotaped selections of you will be presented at parents' nights, academic conferences and in publications, including websites (http://ikit.org) and CDs. You will not be identified by name (a pseudonym will be used) unless you specifically give permission otherwise but it is possible that your identity might become known to others if your image is made publicly available. The original videotapes will be stored in a secure location in an OISE researcher's office and available only to researchers granted with my approval, and fully informed in advance of the Ethics Review Board's documents relevant to this study. The data will eventually be destroyed after the completion of the research study but there is no definite date for this. Upon your request I will be happy to provide a copy of the research report when it has been written.

Your involvement in the research is voluntary. Participation will not influence in any way the evaluation of your performance at school. Also, there will be no negative consequences for choosing not to participate in this research. You may change your mind about participating in the research study and withdraw at any time. If you have any questions about the rights of participants, please contact the Office of Research Ethics at ethics.review@utoronto.ca or 416-946-3273.

If you agree to participate, please complete and sign the attached consent form and return it to me. Please retain one copy of the consent form for your records and return the other. Thank you for considering your involvement in this research project.

Sincerely,

Dr. Marlene Scardamalia

E-mail: mscardamalia@kf.oise.utoronto.ca

Ph: (416) 978-0370

Please complete the form below, detach and return to Marlene Scardamalia, Director, IKIT, OISE/UT, 252 Bloor St. W., 9th Fl., Toronto, ON M5S 1V6

Consent form for "Ways of contributing to dialogue in elementary school science and history" research

Please choose one of the following two options:

☐ I agree to participate in the "Ways of contributing to dialogue in elementary school science and history" research project and I agree that I may be identified in any presentation of this material to the public (i.e. parents' nights, website, CD, conference, publication).

☐ I agree to participate in the "Ways of contributing to dialogue in elementary school science and history" research project but only on the condition that it be on an anonymous basis. I do NOT agree to be identified in any presentation of this material to the public (i.e. parents' nights, website, CD, conference, publication).

____

Printed Name of Participant

____

Signature

______________________________ ______________________________

School Name Date (DD/MM/YYYY)

APPENDIX C—Parent and Guardian Consent Forms

Informed Consent Letter – Parents and Guardians

Dear Parent/Guardian,

I am the Director of the Institute for Knowledge Innovation and Technology at the Ontario Institute for Studies in Education of the University of Toronto (OISE). Since 1986, Dr. Carl Bereiter and I have led a research team at OISE that is developing new instructional materials and technology-based approaches to foster knowledge building and innovation in education.

As part of our current research funded by Social Sciences and Humanities Research Council, we are working to explore how students engaged in collaborative knowledge building develop distinctive contributor roles or styles, and how these roles contribute to a group's success in knowledge advancement. The goal of this research is to develop improved teaching practices that will raise the level of students' explanations and arguments in science and history. We would like to invite your child to participate in this research project.

Your child's participation would involve the following:

1) Occasional videotaping of regular classroom activities by a teacher. The videotapes will be used for analysis only, and never viewed outside a small team of researchers working directly with the principal investigator.

2) Completing a 20-item questionnaire about the reasons for engagement in collaborative inquiry-based project (i.e., knowledge building) activities.

3) Analysis by researchers of contributions your child may make to classroom discussions and Knowledge Forum, the knowledge building software currently used in their class. In order to assess progress in knowledge advancement, contributions will be analyzed using online automated tools available within Knowledge Forum and other qualitative instruments. Automated tools provide statistics regarding contribution rates, reading and writing patterns, semantic analyses, social network patterns and so forth. Qualitative instruments measure the depth of scientific and historical reasoning, depth of understanding and "epistemic complexity", degree of explanatory coherence etc.

If you agree to participate in this research study, your child will not be identified by name (a pseudonym will be used). The original videotapes and questionnaires will be stored in a secure location in an OISE researcher's office and available only to researchers granted my approval, and fully informed in advance of the Ethics Review Board's documents relevant to this study. The data will eventually be destroyed after the completion of the research study but there is no definite date for this. Upon your request I will be happy to provide a copy of the research report when it has been written.

Your child's involvement in the research is voluntary. Participation will not influence in any way the evaluation of your child's performance at school. Also, there will be no negative consequences for choosing not to participate in this research. All students, whether or not they choose to participate, will have access to all regular classroom activities. Your child may change his/her mind about participating in the research study and withdraw at any time. If you have any questions about the rights of participants, please contact the Office of Research Ethics at ethics.review@utoronto.ca or 416-946-3273.

If you agree that your child may participate, please complete and sign the attached consent form and return it to your child's teacher. Please retain one copy of the consent form for your records and return the other. Thank you for considering your involvement in this research project.

Sincerely,

Dr. Marlene Scardamalia

E-mail: mscardamalia@kf.oise.utoronto.ca

Ph: (416) 978-0370

Please complete the form below and return in the sealed envelope to your child's teacher.

Consent form for "Ways of contributing to dialogue in elementary school science and history" research

Please choose one of the following two options:

☐ I give consent for my child to participate in the "Ways of contributing to dialogue in elementary school science and history" research project.

☐ I do not agree to have my child participate in the "Ways of contributing to dialogue in elementary school science and history" research project.

________________________________ ________________________________

Printed Name of Student Printed Name of Parent/Guardian

____

Signature of Parent/Guardian

______________________________ ________________________________

School Name Date (DD/MM/YYYY)

APPENDIX D – Consent Form, ISLS

International Society of the Learning Sciences
www.isls.org

August 9, 2013

Dear Ms. Resendes,

On behalf of ISLS I am pleased to grant permission to reuse portions of the following work in your Ph.D. thesis.

Resendes, M., Chen, B., Acosta, A., & Scardamalia, M. (2013). The Effect of Formative Feedback on Vocabulary Use and Distribution of Vocabulary Knowledge in a Grade Two Knowledge Building Class. In N. Rummel, M. Kapur, M. Nathan, & S. Puntambekar (Eds.) *To See the World and a Grain of Sand Learning across Levels of Space, Time and Scale*: CSCL 2013 *Conference Proceedings Volume 1 –Full papers & Symposia.* Madison, Wisconsin: International Society of the Learning Sciences.

The permission is provided free of charge. The final thesis should include a notice to the fact that it draws on portions of your CSCL2013 paper, for which ISLS owns the copyright.

Best wishes for a successful completion of your Ph.D. and your continued scholarship in the field of the Learning Sciences.

Regards,

Dr. Eleni A. Kyza
Chair, ISLS Publications and Communications Committee
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APPENDIX E—Ways of Contributing to Explanation-Seeking Discourse Coding Guide

Main Categories	Subcategories	Description	Example
Formulating thought-provoking questions	1/Explanation questions	Questions asking "why something happens" or "how does something work"	Why do salmon migrate to other parts of the world?
	2/Design questions	Questions asking how something can be proven or tested through experimentation	
	3/Factual questions	Questions asking "who" "what" "where" or "when"	Where do peregrine falcons live?
Theorizing	4/Proposing an explanation	Student proposes an idea that explains phenomena	I think there are different kinds of birds because they live in a different place and eat different things
	5/Supporting an explanation	Student supports an already existing idea with a reason or justification	[Salmon] like the dark because they're alevins so they think there's predators in the tank.
	6/Improving an explanation	Student improves an already existing idea by elaborating, identifying new details or applying new evidence	The chlorophyll can't get to the leaves so the leaves change their colour. The chlorophyll keeps the leaves green.
	7/Seeking an alternative explanation	Student seeks out a different explanation than those that have been posed	*In response to the theory: "hummingbirds flap fast because they are cold."* [I need to understand]: they would get warmer, wouldn't they?
Obtaining Information	8/Asking or looking for evidence to support a particular idea	Student requests more information or further evidence to verify a theory or idea	
	9/Testing Hypotheses	Student proposes an experiment to test a theory or idea	
	10/Reporting experimental results	Student describes an experiment that was already carried out, or reports details on of ongoing experimental observations	Owls eat lots of things including things NOT in our owl pellets like weasels , for example, they were not in our owl pellets
	11/Introducing new information from sources	Student introduces a new fact or piece of information (that does not support or refute existing ideas but adds to the general knowledge base) from an	Redd means a shallow nest dug into gravel by a female salmon.

		authoritative source	
	12/ Introducing new information from experience	Student introduces a new fact or piece of (that does not support or refute existing ideas but adds to the general knowledge base) that is derived from his/her own experience	*In response to the question "why do birds fly?"* To protect them from predators. My source is from my Nature Notebook. I saw a flock of pigeons flying away from a red-tailed hawk!
	13/Identifying a design problem	Student describes an experiment that did not work and discuss possible reasons why it did not or would not work	[I need to understand]: what happens if one of the fish happens to be born early and they don't get fish food, so we need Chris to help us to get some atlantic salmon food. I THINK WE'LL NEED TO NEED SOME FOOD NOW , so I think I may go get some of it. will they die ?????????????????????????
	14/Thinking of design improvements	Student attempts to improve on a failed experiment and proposes a new and improved design	
Working with Information	15/Providing an evidence or reference to support a particular idea	Student supports a theory or idea using information as *evidence*	In need to understand who does the black feather belong to? My theory is that it belongs to a peregrine falcon because of the black color and it's big and when we watched a movie of it the wings looked big
	16/Providing an evidence or reference to contradict a particular idea	Student rejects or contradicts a theory or idea using information as *evidence*	But waterfalls are so big so salmon cannot jump high enough to get over waterfalls
	17/Weighing explanations	Student assesses different explanations based on specific evaluative criteria	
	18/Accounting for conflicting explanations	Student uses evidence or useful information to account for conflicts or contradictions between explanations	
Synthesizing and Comparing	19/Synthesizing and interpreting information from authoritative sources	Student interprets and paraphrases information from authoritative sources	I think that bird poo is good for the salmon because the poo fertilizes the ground and the fertilizer helps the routs of trees grow bigger and stronger, and then the routs

			hold the mud from going into the water and onto the salmon eggs; because if the salmon eggs get dirty then the might have a chance of dying. I got this from a book called The Life Cycle of A Salmon.
	20/Using an analogy	Students uses a relevant analogy in an attempt to explain or describe something	Birds fly because they are light and there feathers are like parachute
	21/Initiating rise-above entry	Student creates a "rise-above" note that represents a community knowledge advance	
Supporting Discussion	22/Using diagrams to communicate and analyze	Student draws or includes a diagram to visualize an idea or help illustrate an explanation	
	23/Giving an opinion	Student offers his/her own personal thoughts or beliefs about an idea or explanation	My theory is that [salmon] can jump to about 5 feet
	24/Acting as a mediator	Negotiations between students as collaborators rather than on notes/ideas	Why did you make a note with nothing on it?

APPENDIX F—Grade 2 Inquiry Questions: "I Wonders"

"I Wonders" Questions, Grade, 2 2013.

- I wonder how birds can fly?
- I wonder how do they hit the glass?
- I wonder why birds fly?
- I wonder how hummingbirds could fly so long?
- I wonder how do birds fly?
- I wonder how hummingbirds can go 100 flaps per second?
- I wonder where birds came from?
- I wonder if hummingbirds can make nests in 4 minutes?
- I wonder how to tell a female bird to a male bird?
- I wonder why birds' bones are hollow?
- I wonder how can a bird fly so far?
- I wonder if hummingbirds could flap their wings 100 times every second?
- I wonder why birds are so different?
- I wonder how peregrine falcons go 150 miles per hour?
- I wonder how humming birds can fly so long so fast without falling down?
- I wonder how they make nests out of twigs, leaves, and grass?
- I wonder how birds make their nests?
- I wonder how birds look when they are in their eggs?
- I wonder how do hummingbirds flap 100 times per second. How do you know if female or male?
- I wonder how can humming birds flap their wings 100 times in a second?
- I wonder how birds fly?
- I wonder how high can they fly?
- I wonder how birds fly without stopping?
- I wonder how they fly?
- I wonder why birds are different from other birds?

APPENDIX G—Domain Words Vocabulary List

abiotic	artery	classified	disease	explore	
above	atmosphere	classifies	diseases	explores	fry
adapt	attract	classify	diseasing	exploring	function
adaptation	attracted	classifying	distance	falcon	functioned
adapted	attracting	clay	distances	falcons	functioning
adapting	attraction	climate	diverse	feather	functions
adapts	attracts	colour	dormant	feathers	fur
aerodynamic	balance	comet	downstream	ferns	gene
aerodynamics	behaviour	comets	drag	fertilizer	generate
aeronautical	behaviours	communities	drought	fertilizers	generated
affect	beside	community	droughts	filter	generates
affected	biodegradeable	compare	dynamic	filters	generating
affecting	biodiversity	compared	earthquakes	filtration	generator
affects	biofuel	compares	economy	flapping	generators
air	biological	comparing	ecosystem	flexible	genes
airflow	biosphere	compost	ecosystems	flight	geothermal
airfoil	biotic	composter	effect	float	germinate
airfoils	bone	composters	effects	floated	germinated
alevin	bones	condition	efficiency	floating	germinates
alevines	breathing	conditions	efficient	floats	germinating
algea	breed	conservation	eggs	flood	gizzard
alike	breeds	conserve	element	flooded	glacier
alevin	build	conserved	elements	flooding	glaciers
Altantic	builds	conserves	endanger	floods	glide
amphibian	built	conserving	endangered	flower	glides
amphibians	carbon	construction	endangering	flowers	grasses
angle	carnivore	consume	endangers	fluid	gravel
angles	characteristic	consumed	energetic	fluids	greenhouse
anthropodes	characteristics	consumes	energy	food	greenhouses
application	chemicals	contamination	engineered	form	groundwater
applied	Chinook	control	environment	formation	grow
applies	chlorine	controlled	environment	formations	growing
apply	circulate	controlling	erosion	forms	grown
applying	circulated	controls	experiment	foundation	grows
aquifer	circulates	criteria	experimenting	foundations	habitat
arteries	circulation	cycle	experiments	freshwater	habitat
habitats	interrelationship	mine	organic	primates	resists
habitats	interrelationships	mines	organics	process	resource

hatch
health
healthy
heat
height
herbivore
herbivores
hibernate
hibernated
hibernates
hibernating
hurricane
hurricanes
hydrodynamic
hydrometer
hydrometers
increase
increased
increases
increasing
indigestable
individuals
insect
insects
insulate
insulated
insulates
insulating
interact
interact
interacted
interacting
interaction
interacts
interdependent
interrelated
similarity
size
sizes
sludge
intestine
intestines
invasive
invertebrate
invertebrates
investigate
investigated
investigates
investigating
irreversible
landscape
landscapes
landslide
landslides
leaf
leaves
life
lifespan
lift
light
living
living systems
loam
magnitude
mammal
mammals
material
materials
micro-organism
micro-organisms
microclimates
microscopic
migrate
migrated
migrates
migration
surfaces
survival
survive
survived
mining
modified
modifies
modify
modifying
motion
movement
movements
native
natural
natural
natural
nature
navigate
navigated
navigates
navigation
need
needing
needs
negative
non-renewable
nutrient
nutrients
nutrition
object
objects
observation
observe
observed
observes
observing
ocean
omnivore
omnivores
organ
tsunamis
type
types
upstream
organism
organisms
organs
output
oxygen
ozone
Pacific
parr
perspective
perspectives
pesticide
pesticides
photosynthesis
pistil
pistils
polar
pollen
pollute
polluted
pollutes
polluting
pollution
population
population
populations
populations
positive
precipitation
predator
pressure
pressured
pressures
pressuring
prey
primary
primate
processed
processes
processing
producer
producers
propulsion
purpose
purposes
react
reacted
reacting
reacts
redd
regulate
regulated
regulates
regurgitate
regurgitated
regurgitates
regurgitating
relate
related
relates
relating
renewable
renewables
reproduce
reproduced
reproduces
reproducing
reptile
research
resist
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resources
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return
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returns
rivers
rock
rocks
rodent
rodents
root
roots
round
runoff
salt
sandy
saturated
scavenger
scavengers
season
seasons
seedlings
settling
shape
shaped
shapes
shaping
shear
shelter
sheltered
sheltering
shelters
similarities

smog
smolt
smolts
society
soil
source
space
spaces
spawn
spawning
species
sped
speed
speeded
speeding
speeds
spit
stage
stages
steer
steered
steering
steers
stem
stems
steward
stewardship
streams
sublimation
succession
support
supported
supporting
supports
surface
survives
surviving
sustain
sustainability
sustainable
sustained
sustaining
sustains
system
systems
technique
techniques
temperature
temperatures
theories
theory
thermal
thrust
tide
tides
tie
ties
tilt
tornado
tornadoes
toxic
transfer
transferred
transferring
transfers
transform
transformed
transforming
transforms
tsunami
upstroke
vertebrate
vertebrates
warmth
waste
wasteful
water
web
webs
wingspan
zooplankton

APPENDIX H—"Big Ideas" Final Quiz

1.) Where do falcons come from?

- They just appeared from things like eggs or seeds
- They came from dinosaurs
- An eagle mated with a hawk and produced a falcon
- Humans created falcons by breeding them in laboratories

2.) Why are hummingbirds different from penguins?

- They were just created differently and they have always been different
- A sparrow and a finch mated and produced a hummingbird
- They have always lived in two different habitats so they are a different species
- They have a common ancestor but have changed into two entirely different species over time

3.) Look at image #1. What characteristics does an animal need to survive in this environment?

- Webbed feet
- A heavy fur coat
- Nimble hands for climbing
- A long tail
- Wings

4.) Look at image #2. What sorts of physical characteristics does the Spiggle animal possess?

- Webbed feet
- A heavy fur coat
- Nimble hands for climbing
- A long tail
- Wings

5.) Look at image #3. What happened to the Spiggles after the island became covered with water?

- All the Spiggles survived and adapted to their new environment
- Some Spiggles survived and adapted to their new environment
- All the Spiggles died out because they can't live in water
- The Spiggles left the island and now live somewhere else

6.) Guess what! Scientists discovered that there were some creatures they thought were Spiggles still living on the water-covered island. How do you think they survived?

- All the Spiggles survived. They all learned how to swim, and so they were able to survive in that new environment.
- All the Spiggles survived. They all started to get webbed feet and passed the characteristic of webbed feet onto their babies.
- Some of the Spiggles survived. Only the Spiggles that had smaller feet and longer bodies were better at swimming, and so they survived. The shorter, long-fingered Spiggles that weren't very good at swimming died out and became extinct.

7.) The big changes that occurred to the Spiggles' natural habitat affected them greatly—some Spiggles died out and others adapted to their new environment. Atlantic salmon are also experiencing changes to their environment. What are some examples that represent changes to a salmon's environment?

- Warmer, slower-moving water
- Loss of trees and a lot of water pollution
- Warmer air temperatures because of global warming
- All of the above
- Answers 1 and 2

9.) Can Atlantic salmon adapt to the changes that are occurring in their environment?

- Yes
- No
- Maybe
-

10.) What would have to happen for Atlantic salmon to adapt to one environmental change, specifically slow-moving water?

- Salmon could not adapt because they need fast-flowing water to survive. If the water was slow they would not be able to survive.
- Only the salmon that had long, strong tails and could swim fastest would survive. The salmon that had shorter tails and couldn't swim as fast would die.
- The salmon would have to learn to swim faster, and this trait would be passed on to their babies.
- Animals go extinct unless people help them to adapt.

11.) What is the most important thing we can do to help protect the salmon?

- Make sure that the salmon's natural habitat does not change too much
- Breed a lot of them in captivity
- Stop overfishing and littering so they will naturally repopulate