The Knowledge Building Approach to Science Education: A Problem-Solving
Perspective

A Dissertation
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA
BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Gillian Roehrig, Advisor

August, 2019

Acknowledgements

…on following page…

Dedication

This thesis is dedicated to my family: my parents, John and Virginia Groos; my sisters, Julia, Katherine and Annette – together they have taught me, and continue to teach me, about the meaning of family; and to my extended family near… and far; to my friends and family in Guatemala, especially Mama Mincha & Papa Chico; to my childhood, and now adult, friends: Tim and John, Bill, Hugh, Jim, Paul, Peter and Steve; to my further friends, teachers, colleagues and collaborators who have shared this journey; to my many students and teachers, especially John K, Fred N and Jean L; to the good people who have shared their ideas and time and supported my efforts from Finland and Greece and more.

To my advisor, Gill Roehrig, who has been dedicated to my success these last 14 years, focused and open-minded and smart; I would not be here today if not for her.

And finally, I dedicate this work to my Family. My children John so smart and growing all the time, Emily, my eternal flower and Erika, my first child who is still teaching me to be a dad. And finally, to my wife who has been more dedicated to me than I can hope to ever deserve, Thank you Maria Luisa Groos.

Abstract

Science education is reasonably constructed around a vision of authentic scientific practices. Yet, this vision of science is clearly a construct as seen when viewing its changes throughout the last 120 years, as well as viewing it through different theoretical perspectives. While there are diverse descriptions of science and its enactment, going back to Dewey and Peirce, the mission of science is commonly considered to be about the advancement of theory through inquiry where problems serve a central function.

Beyond the challenge of constructing an understanding of scientific inquiry as theory development where the diversity in perspectives of scientists is seen as essential, there is the challenge of devising pedagogy and approaches that effectively promote this vision. There are a rich mix of approaches working at solving different parts of this complex problem. One such approach is called, "knowledge building" (Scardamalia and Bereiter, 2006). This approach seeks to scaffold classroom communities such that they develop and grow into a complex community where progressive science-theory improvement emerges. It is considered that these sorts of communities where innovation is the norm have relevance beyond the fields of science and STEM: innovation and knowledge creation is becoming the essential practice of the knowledge age.

The knowledge building approach is designed to support the growth of classroom communities that embody the essential nature of progressive scientific inquiry. To effectively support this kind of classroom community development, the unique assets and needs presented by the ever-increasing diversity of thinking and knowing that are emergents of the students' cultures, developmental levels, neurological diversities and

networks of communities. Overall, this research sought to support and augment classrooms as they strive to grow into classroom communities of scientific inquiry.

The research occurred in two stages. It first used philosophical methods to generate a simple, high-level model of problem-solving made possible by Popper's World-3 conception. This conception is a keystone in some epistemologies developed to support approaches aimed at helping students grow in knowledge-innovation practices. The visual problem-solving model that was developed seeks to provide students and teachers with a very simple yet flexible model allowing them to describe, analyze and reflect on the state of their community's knowledge improvement and through this understanding adaptively and effectively respond.

The second stage of research utilized hybrid philosophical-empirical methods to develop a framework that describes science in terms of its mission to progressively improve theory through the iterative solving of and subsequent unfolding of new knowledge-problems. These research methods involved an iterative process where promising theories are tested on their ability to describe students' actual online knowledge-building discourse in a satisfying way. In this iterative process, empirical classroom data informed and yet also constrain the theory generation which was informed by diverse theoretical perspectives. These theoretical perspectives included for example, ideas of scientific practices, theories of design such as design thinking and understandings of classroom diversity as represented in the Next Generation Science Standards (NGSS Lead States, 2013) which were intentionally founded upon theories of

culturally responsive pedagogy. The developed framework seeks to scaffold teachers as

they design and enact lessons aimed at growing communities of diverse scientists. Taken

together, the products of this research seek to provide conceptual structures to aid the

students and teachers in classroom communities as they seek to grow into complex

communities of scientists.

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1 Rationale

The Knowledge Building approach: transforming science classes into diverse communities of scientific inquiry

1.1 Standards combined provide vision of authentic scientific inquiry

Coming in excitedly from recess, the fifth grade…

"…students pointed to three trees growing side by side. One had lost all its leaves, the middle one had multicolored leaves – mostly yellow – and the third had lush, green leaves. The children said, "Why are those three trees different? They used to look the same, didn't they?" (National Research Council, 2000, p. 6).

These lines initiate the story of a class of students starting on a scientific inquiry. This five-page classroom vignette in *Inquiry and the National Science Education Standards* (National Research Council, 2000) seeks to establish the standard's vision of scientific inquiry in the classroom. The story goes on to tell how the students explored the problem and developed a set of hypotheses as to the cause of the problem. In self-organized groups, students devised ways to test their ideas, and through sustained inquiry, they concluded that the problem was probably caused by a new watering schedule by the school custodian. Presenting their research to this custodian caused him to revise his method. The students predicted that, if their explanation were correct, next year they should see all three trees flourishing. Which, as it turned out, they did.

Two things stand out in this vignette. First, while the teacher scaffolded students' discussions and activity, it was the students' individual and collective epistemic agency that solved their problem. Second, this was not a single activity or single iteration of

experimental inquiry but an extended inquiry involving numerous iterations of questions

and answers, requiring whole-class and small-group dialogue, persevering through dead

ends, and finding deeper and more sophisticated questions. This was a complex

classroom enterprise requiring the posting of epistemic artifacts, e.g., lists of working

explanations in public spaces, authentic use of authoritative resources such as a local

nursery, inter-group research critically shared. Rich dialogue mediated their inquiry

throughout. The explanation students developed to their question, "Why are the trees

dying", afforded them the power to solve *their* dying-trees problem. Their extended

inquiry provided the deep and rich understanding of the real-world connections between

the environment and human activity. This could be considered problem-centered

learning.

      Another vignette in the first chapter concerns a geologist's inquiry, starting:

> *A geologist who was mapping coastal deposits in the state of Washington was surprised to discover a forest of dead cedar trees near the shore. A significant portion were still standing, but they clearly had been dead for many years. He found similar stands of dead trees at other places along the coast in both Oregon and Washington. He wondered, "What could have killed so many trees over so wide an area?" (National Research Council, 2000, p. 1).*

This vignette told the story of a geologist and how his research problem transformed over

time through his and his colleagues' epistemic agency. Discovering deeper, world-

spanning patterns these scientists developed a model identifying the frequency of severe

tectonic events. This model initiated a change in building codes in two states. This

vignette presented a strikingly similar image of scientific inquiry to that of the students in

the first case study and their tree problem. Taken together, these two stories illustrate one

of the four NSES foundational principles of these science education standards: "School

science reflects the intellectual and cultural traditions that characterize the practice of

contemporary science." (National Research Council, 1996, p. 19).

The Next Generation Science Standards (NGSS Lead States, 2013) aimed to

address the "colorblind" perspective of the previous standards (Gallard, Mensah, & Pitts,

2014; Rodriguez, 2015). Also using vignettes to communicate the vision of these

standards, seven Case Studies clearly illustrated this important advancement of the NGSS

over the NSES (NGSS Lead States, 2013). For example, Case Study 2 illustrates a vision

of science pedagogy that stems from a culturally relevant perspective. It advances the

vision of science education in a new dimension by acknowledging both the needs and

opportunities of student diversity in the classroom (Ladson-Billings, 1995). The

following observation presented in the case study conveys the rich discourse displayed

throughout the vignette of a middle school science class studying ideas related to energy

and matter while engaging in science practices:

> *"Nayeli added her experience with oil rigs: "The air has a smell; it's like heavy. Sometimes I could feel oil in the air. The oil in the air sticks to you, and it messes with your hair." She had recently moved from Texas" (p. 3)*

This case study presented a system of activities taking place over several days. These

activities created a complex network of people and ideas, things, events and places which

held personal relevance to the individuals in the class, such as Nayeli's realization that

the oil "messes with" her hair. This network was constantly elaborated and strengthened

through authentic discourse and question-driven engagement. In part, this was made

possible because the classroom norm was respect among students and between the teacher and students.

1.2 The combined vision of scientific inquiry in the classroom

These three vignettes illustrate complementary aspects of a vision of a science education for the current era, the knowledge age. Science understood through the integration of these three vignettes places central importance on rich and complex personal connection through sustained, question driven inquiry. This vision of science, and therefore science education, is ideally situated to nurture and guide students in their capacity to creatively, critically and collaboratively develop solutions to complex problems in their world. This vision describes scientific inquiry in the classroom at its best. The research presented here seeks to move forward an approach developed three decades ago (Bereiter, 2002; Chen & Hong, 2016; Scardamalia & Bereiter, 1993) designed to facilitate this combined vision science education. In this approach, students' sustained epistemic agency channeled through Knowledge Building dialogue and materially embodied practices progressively develops theory to understand their world.

Instantiating the vision presented in Case Study 2 is challenging. However, theoretical frameworks are developing to understand, create, and test pedagogies and engaged curricula at different levels of the educational infrastructure of the United States. In other words, the path to realize that vision is available and in different stages of progress already (need to cite that one!) However, solving the practical pedagogical problems involved with sustaining ongoing practices of scientific inquiry, such as that

envisioned in the first vignette of the classroom seeking to save the three trees, are daunting. Authentic problems such as the local tree problem are difficult to come by. Furthermore, if a teacher is responsible for multiple classes of students which is typical in middle and high school, managing the emerging activity of such a wonderful real-world problem in as many as five classes would be nearly impossible. Likewise, if one attempts to divide a single, real world problem between several classrooms, managing the complex interactions while also assuring student achievement would also be improbable. However, the theoretical and pedagogical framework Knowledge Building, designed to instantiate age-appropriate communities of scientific inquiry in culturally rich communities already exists, although is not well-known in the United States.

1.3 Three decades in development: a pedagogical approach aiming at this vision

Originating at the University of Toronto in the late 1980s and spreading to Finland, Hong Kong, Singapore, China, Japan and more in the late 1990s and early 2000s, "Knowledge Building," or "KB," is an approach exactly aimed at a science education where students instantiate a community of scientists, taking charge of their inquiry over an extended time (Chen & Hong, 2016). It is centered around supporting sustained, student-led scientific inquiry and enhanced by the enactment of classroom diversity and democratic principles. By examining the list of "12 Knowledge Building principles" (Table 2.1) that define and serve as high-level analytical tools of this approach, one can see its scope as it works to to realize this complex vision: Real ideas, Authentic problems; Improvable ideas; Idea diversity; Epistemic agency; Community

knowledge, collective responsibility; Democratizing knowledge; Symmetric knowledge

advancement; Pervasive Knowledge Building; Constructive use of authoritative sources;

Knowledge building discourse; and Embedded, concurrent and transformative assessment

(Scardamalia, 2002).

1.4 Filling gaps by increasing approaches' "graspability"

From the perspective of a classroom teacher, the "problem" of developing a

complex system in which the students in a classroom grow into and thrive as a

community of scientific inquiry as described above has the characteristics of a "wicked

problem" (Leinonen & Durall, 2014). Wicked in this sense does not refer to evil, but

complexity. The term in 1973 by whirl and riddle introduced the class of problems

distinguished from closed problems such as those familiar in math class, riddles and so

on where there is one correct or best answer. Typical examples of wicked problems

include global warming, new car design and pollution. Characteristics of wicked

problems include (Conklin, 2005, pp. 14–15): 1) You don't understand the problem until

you have developed a solution; 2) Wicked problems have no stopping rule; 3) Solutions

to wicked problems are not right or wrong, they are simply 'better,' 'worse,' 'good

enough,' or 'not good enough.' Furthermore, a characteristic of wicked problems is that,

"What 'the Problem' is depends on who you ask – different stakeholders have different

views about what the problem is and what constitutes an acceptable solution" (Conklin,

2005, p. 14). Because of this last characteristic, the following identified gaps in the

Knowledge Building literature are from the perspective of a classroom teacher seeking to

instantiate the Knowledge Building approach in his classroom. Furthermore, this teacher's work was not scaffolded by Knowledge Building researchers, but only KB literature and pedagogical guides available on the web. Consequently, these gaps should be seen to identify and validate the needs of teachers. With this in mind, the following three gaps in literature are identified.

This current research aims to address three gaps in the literature. The first gap is the need for *a simple visual model of a single iteration of the basic question-answer problem-solving view of Knowledge Building*. This visual model would serve as a heuristic to aid students and teachers in understanding the basic principle of knowledge improvement as a cyclical process involving epistemically-opposing activity and the resultant, World-3 knowledge objects developed. This model would provide a general yet useful answer to the question "How do you build knowledge?"

Second, there is currently no system to *visually represent the connected, multiple iterations, of this basic problem-solving cycle that occur in sustained inquiry*. This is a problem as, without such a system there is no way to visualize the unique branching patterns of the iterative question–answer cycles that emerge through Knowledge Building and thereby understand the sustained, community-wide nature of collaborative knowledge improvement. Furthermore, without this conceptualization of progressive, branching knowledge improvement where problems transform and questions unendingly unfold, there is no clear connection between problem-solving which emphasizes developing an answer or solution to a problem, and inquiry whose hallmark is an un-

ending quest for understanding. In filling the first and second gaps identified above, a pathway is suggested to reclaim the ideas of "research problems" and "problem-solving", providing needed structure to the conception of inquiry in high school science.

A third gap in the literature is the lack of a *descriptive framework* to structure our thinking around the epistemically distinct types of problems with which a science Knowledge Building community needs to engage. Also lacking is an epistemically structured model of engagement consistent with both creative and critical models of goal-oriented epistemic activity centered around solving problems in the above-mentioned science problem-types. And alongside this epistemic goal-centered activity a political goal-centered activity of building community around ideas is also called for. Finally, a framework, from a problem-solving perspective of Knowledge Building, would provide a visual model of knowledge improvement and thereby provide a structure to connect the two basic components of inquiry: questioning and answering. This last level of the framework would scaffold elaborating and testing specific sets of scripts that is, sentence starters, that support students' knowledge work. Taken together, the products developed through this research seek to address these three gaps and provide a way for teachers as well as students to understand and navigate a problem-solving view of Knowledge Building in the classroom, that is, make the KB approach more accessible to teachers and students. It is hoped furthermore to provide a structure to mediate productive discourse around Knowledge Building pedagogy and supporting technology between teachers and researchers.

"What is a descriptive theory of Knowledge Building in the science class in terms of types of problems, epistemic and social aims that take into account the ideas of design and belief mode and the need to develop consensus around theories, along with problem-solving and specific knowledge types?"

2 Literature Review

Sections 2.1 and 2.2 provide the theoretical foundations from which answers to research questions one and two are argued in section 2.3. The knowledge presented in 2.1 and 2.2, along with the models argued in section 2.3 provide the conceptual tools required to address research question three which will be addressed in chapter 4 through hybrid philosophical/empirical methods. Research question one seeks a simple conception of the core activity of Knowledge Building, that is, knowledge improvement:

> *How can the process of knowledge improvement in science from a problem-solving perspective be succinctly described?"*

As this is not an empirical question it will be argued from the literature. The model that was developed as a solution to the first research question was an iterative, problem-solving model of knowledge improvement. This visualization served as a design element in the developed solution to the second research question:

> *How can a class' actual, unfolding, progressive-inquiry dialogue be mapped?"*

The mapping system developed as a solution used a simple rule-based visual logic to determine how the "child" cyclical model emerges from the parent cycle. The map of the extended knowledge-building discussion emerged as an indefinitely-extensible branching structure: flexible yet rule-based. These models satisfy criteria of 1) being theoretically-anchored, solidly; 2) serving as a low cognitive load visual heuristic of knowledge-improvement dialogue of value to both teachers and students; 3) promising

potential for use in software systems that scaffold complex systems of interconnected iterations of problem-solving episodes of the different yet related STEM disciplines.

These two knowledge improvement models served a foundational role in answering the third and final research question:

> *What is a descriptive theory of a problem-solving view of Knowledge Building in a high school science classroom?"*

Answering this third research question required hybrid philosophical/empirical methods and is developed in Chapter 4.

An overview of the history of the view that science is a problem-solving endeavor is presented in section 2.1. This overview includes Popper's important invention, the idea that knowledge can be considered to be real, albeit abstract, objects, a foundational concept in knowledge-creation epistemologies (Paavola & Hakkarainen, 2005). Section 2.2 uses the ideas introduced in 2.1 to develop and elaborate the knowledge creation approach to science education, specifically Bereiter and Scardamalia's Knowledge Building approach and their ideas of "design mode" engagement, the primary mode responsible for innovation in the knowledge age. Finally, Section 2.3 presents the solutions developed to research questions one and two.

The first solution, the "knowledge improvement cycle" (KIC), integrates the above described concepts to visualize Knowledge Building discourse from a problem-solving perspective. This four-part iterative cycle is centered around the problem that is to be solved. In this context progressive inquiry, a pedagogy integrating the KB approach with Hintikka's interrogative model of inquiry, is presented.

The second solution, the "knowledge improvement map" (KIM), is a simple

system of graphical rules based on the possible relationships within the question-answer

iteration described by the interrogative model and visualized in the KIC. Following these

graphical rules, a map of a Knowledge Building dialogue emerges. In other words, the

KIM visualizes Knowledge Building discourse: a map of the extended inquiry. The map

indicates the sequential connections between the emerging question and answer

knowledge-objects. And as these knowledge objects are embedded in their respective

knowledge improvement cycles with the questioning and answering activities that

produced them, the map allows one to trace the development of the knowledge objects

produced in the unfolding dialogue.

2.1 Philosophy of science: science is problem solving

Considering science as a form of problem solving is common in the philosophy of

science. This view is clearly expressed by Lakatos, Worrla, and Zahar (1976): "…a

scientific inquiry 'begins and ends with problems'" (p. 111). Laudan (1978) in *Progress*

and its Problems: Towards a Theory of Scientific Growth states: "Science is essentially a

problem-solving activity" (p.11). That science is a problem-solving activity has a long

and rich history of development by many philosophers of science, from Peirce and

Dewey to Popper to Hanson and Kuhn, solidifying the stature of that view. Furthermore,

science education researchers and innovators such as Bereiter and Scardamalia,

Hakkarainen and Paavola, Brown and Kolodner and have developed approaches to

science education where problems and their solving occupy the center stage. In

consonance with this pervasive philosophical view, it is argued that scientific inquiry, i.e., "the diverse ways scientists study the world…" (National Research Council, 2000) is a form of problem solving.

2.1.1 Charles Pierce and John Dewey and the problems of science

Charles S Peirce was a practicing scientist for most of his adult life, as well as a mathematician, logician and philosopher of inquiry. Of particular interest is Peirce's work on the logic of discovery and his idea of abduction, the process by which promising hypotheses are generated in order to solve problems. Pierce conceptualized abduction in two ways. In his earlier years he saw it as inferential (implying a 'logic' of discovery) and in the latter two decades of his career he also saw it as instinctual, i.e., intuitive-guessing. Regardless, Peirce saw abduction as "…an essential element of the first phase of inquiry where ideas are originated for subsequent testing" (Paavola, 2007). These hypotheses can be tested through empirical or philosophical methods however abduction is "…the only logical operation which introduces any new idea (Peirce, 1974, vol. 5.172). Peirce contrasts the process of abduction, sometimes referred to as 'inference to the best explanation" to both the processes of induction and deduction (Lipton, 1991):

> *Abduction is the process of forming an explanatory hypothesis. It is the only logical operation that introduces any new idea; for induction does nothing but determine a value, and deduction merely evolves the necessary consequences of a pure hypothesis (Mullins, 2002).*

However, in the process of generating a hypothesis through abduction, we often refine the abductive hypothesis through deduction and induction leading to an abductively-arrived-at improvement in the hypothesis (Mullins, 2002). Finally, Pierce did

not see abduction as only used to generate a conjecture but also more broadly as a "class of thought that leads to problem formulation; it fuels human inquiry (Mullins, 2002, p. 200)". In conclusion, Pierce viewed scientific inquiry as a problem-solving process that involved both logical and intuitive processes. His ideas continue to be foundational for modern philosophers and science education researchers including Paavola, Sintonen and Hakkarainen.

Dewey, a philosophy student of Pierce, also considered scientific inquiry to start from a "problem" which demanded an explanation for its resolution. In *Logic: The Theory of Inquiry*, Dewey (1938) advanced problem solving as the context for his theory of inquiry. Like his mentor, Pierce, he considered problems to be subjective and psychological. Problems were considered irritations and a frustrating psychological state of doubt. This state of mind typically occurred when something unexpected happened <u>and</u> one felt the need to find the significance of this unexpected occurrence (i.e., because there was the sense that this event was important). This need could be motivated by values that are practical, e.g. "if it rains then I'll need to change my plans" or aesthetic e.g. "if the earth is a sphere that means people on the other side of the world are upside down". This problematic fact seeks a theory to make it understandable and therefore no longer a problem.

To understand Dewey's theory of inquiry it is helpful to start with the definition of inquiry that he advanced in the later parts of his career. Dewey (1938) argued: "Inquiry is the controlled or directed transformation of an indeterminate situation into one that is so

determinate in its constituent distinctions and relations as to convert the elements of the original situation into a unified whole" (p. 105). In other words, he is saying that inquiry is the solving of a problem of understanding or knowing, experienced as a state of cognitive conflict, similarly described as one of the important parts of conceptual change (Guzzetti, Snyder, Glass, & Gamas, 1993). The solving of the problem can be considered a transformation of the problematic state of understanding or knowledge causing the psychological state of disequilibrium into one of equilibrium. As such, problem solving is an extremely broad category of activities that applies to not only the most sophisticated forms of scientific research, but even to the food seeking behavior of single celled creatures, as well as the collaborative problem-solving studied in science education literature (Koschmann, 2002). As will be seen, Popper shares this broad interpretation of problem-solving.

2.1.2   Karl Popper and science as iterative problem solving

Like Dewey and Pierce, Popper explained problems as the starting place of scientific inquiry. He located problems not in the psychological experience however, but as inevitable entailments of theories which he sometimes referred to as solutions. These problems exist in the logical relationships between propositions, either as a gap in knowledge or inconsistency within our knowledge system. This is consistent with his continuous effort to de-psychologize the process of science. He therefore asserted that the scientist's job was to detect and resolve theoretical contradictions that is, problems (Popper, 1959).

According to Thornton (2018), Popper saw "problems" and "problem-solving" as broadly applicable: "Science, like virtually every other human, and indeed organic, activity, Popper believes, consists largely of problem-solving" (The Problem of Demarcation). Popper posited problems to be at the center of scientific inquiry, or more precisely that science always starts and ends with a problem. He felt that theories are attempts to explain or solve problems. He argued that theories could not be proven to be true, only proven to be false. Popper's four-stage logical model of problem solving is as follows. First, a Problem is noted (P). Second, a Tentative Theory (or Tentative Solution) is proposed that both: a) solves the problem and b) is falsifiable (TT). Third, in order to perform Error Elimination, an empirical test whose positive result would indicate an error in the tentative theory is performed (EE). Fourth, ideally an error is found revealing a previously unknown weakness in the theory, thereby affording the knowledge needed to redefine or transform the initial Problem (P'). This new problem can then launch a new problem-solving episode. He argued that this process did not result in proven theories but simply theories that had survived all tests so far. However, Popper reasoned that ideas that had gone through many iterations of this error-elimination process and withstood extensive attempts to falsify them should be considered to be less likely to be false, i.e., more reliable.

Popper developed his "tetradic schema", a schematic representation of the above delineated problem-solving process: Problem → Tentative Theory (or Solution) → Error Elimination → New Problem. He used this problem-solving model to argue many ideas,

primarily his solution to the problem of demarcation: distinguishing between science and non-science, for example, pseudoscience. However, he also used it in diverse contexts, for example to explain, "The growth of knowledge – the learning process (1972, p. 144)" and his restatement of Darwin's theory of evolution (1972, p. 243). This model was commonly represented in abbreviated form: P --> TT --> EE --> P', as shown in Figure 2.1. In conclusion, it cannot be overstated the importance Popper places on problems and problem-solving in science: "The centrality and priority of problems in Popper's account of science is paramount, and it is this which leads him to characterize scientists as 'problem-solvers'" (Thornton, 2018, sec. The Growth of Human Knowledge).

$$P_1 \rightarrow TT \rightarrow EE \rightarrow P_2$$

Figure 2.1 Popper's "tetradic" representation of problem solving.

In the US science education community, Popper is most famous for his work on the idea of falsification as described above and its role in the process of developing reliable knowledge. The three-world ontology he developed to adequately support these arguments is much less known, though it provides philosophical concepts being used to re-think science education. An ontology tells basically two things, first, "*What there is, what exists, what ... reality is made out of, secondly, [it] say[s] what the most general features and relations of these things are*" (Hofweber, 2018, sec. Different conceptions of ontology). Popper argued that it is useful to consider that we live and work in three separate, though interrelated, "worlds" (Popper, 1972). In Popper's ontology, World-1 (W1) consists of physical or material things, equivalent to how we often conceptualize

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the real physical world. World-2 (W2) is composed of a person's knowledge and beliefs, ones "mental states". While Worlds 1 and 2 were well established in western conception, World-3 was however unusual. He argued that we ought to consider that the abstract cultural products of human activity exist in their own world, World 3. World-3 (W3) then is composed of "cultural artifacts" including not only scientific theories, laws and concepts, but plans, processes, language and things as mundane as recipes. He argued that we can conceive of these objects as having as real, albeit abstract, existence as any physical object in World 1. Although Popper initially introduced his 3-world ontology in 1960, it was not until 12 years later that he fully elaborate it in his book, *Objective Knowledge* (1972). Boyd (2016) goes as far to state that, "His world 3 proposal, once fully shaped, became a keystone of his thought, holding its arches together, unifying and extending his ideas" (p. 2). This foundational significance of Popper's 3-world ontology is shared by both the Knowledge Building and progressive inquiry approaches that aspire to enculturate students into knowledge-age practices (Bereiter, 2002; Paavola & Hakkarainen, 2005). Indeed, it is the concept of W3 that permitted the development of the solution to research question one, and therefore is also an essential component in the answers to research questions 2 and 3.

In their work with Popper's W3 conception, Bereiter and Scardamalia (1996) have addressed a misconception concerning Popper's "Objective knowledge" saying, "What he meant was not "objectively true" or "free of subjective bias." He meant, simply, treatable as an object" (p. 493). Bereiter (2002) elaborates: "World 3 is not limited to

accepted, verified, or important knowledge objects. It can include discredited theories, crank notions, unsolved problems and new ideas that may or may not gather a following" (p. 236). Popper's 3-world ontology allows us to analyze and understand how "knowledge work," such as science, is done, and furthermore lays the foundation for developing approaches to how the knowledge work of science can be instantiated in classrooms. The idea of W3 as the space where the problems addressed by science are solved, along with Popper's idea of iterative problem solving and the ideas of Knowledge Building will be extensively developed in section 2.2.

2.1.3 Hanson and Kuhn: scientific problems exist in our Gestalt

Contemporary to Popper's work, Hanson problematized the nature of knowledge and created the bridge from the work of Popper to that of Kuhn, whose work was a "major force in bringing about the final demise of logical positivism" (Bird, 2018, sec. 6.5). Nonetheless, while Hanson's views of science differed from Popper, both considered science to be about the solving of problems. Hanson's work was not explicitly about the process or methodology of science. However, through his writings it is clear that he understood science to be about solving problems. As Hanson makes his argument that observations are theory-laden he gives many examples of famous scientists and their work, explicitly describing their work around research problems.

One could consider the difference between Popper's and Hanson's view on problems to center around where they considered problems to be located. Popper felt that problems were situated in both W1 and W3. On the other hand, Hanson believed problems to exist in our mind. To Hanson, inquiry starts with the experience of

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anomalies, i.e., surprising or astonishing phenomena, creating the need to explain, not unlike Dewey. In other words, both philosophers view problems to exist in W2, in our mental states. Hanson applied the ideas of the Gestalt school of psychology to W2 and to science knowledge development.

Influenced by the Gestalt school of thought, Hanson described the role of theories in our mind as constitutive that is, our theories or as Kuhn was to say our paradigms, the way we understand the world influences what we see. To illustrate his thesis, Hanson proposed a thought experiment where Johannes Kepler is standing next to Tycho Brahe on a hill at dawn, watching the sunrise. Kepler regarded the sun as fixed and that the earth moved around it while Tycho's view followed that of Ptolemy and Aristotle and that the earth's location is fixed and that all celestial bodies including the sun moved around that. Then Hanson asked, "*Do Kepler and Tycho see the same thing in the East at dawn?*", developing the argument that they would not (Italics in original work, (1958, p. 5). Hanson situated this idea of Gestalt switches in the context of scientific thinking, creating a key concept in the philosophy of science, that observation is "theory laden". This concept caused substantial damage to the correspondence view of truth. "Problems" no longer existed in W1, but in W2. World 3 is where we do knowledge work solving these problems of understanding. In conclusion, even though both Hanson and Popper argued for new (and different) ontologies of science, they both saw problems and problem-solving playing an important role in science.

Thomas Kuhn, like Hanson, considered scientific inquiry to be about solving problems, indeed he discusses his own inquiry in terms of problems (e.g. (T. S. Kuhn, 1970, pp. v–vii)). In addition, they considered these problems to be located in the world of the mind. Kuhn (1962) first published his thesis on *The Structure of Scientific Revolutions* just four years following Hanson's publication explaining the logic of scientific discovery in terms of Gestalt theory. Kuhn develops the argument that theory laden observation occurs not only in simple situations, but also in scientists' practice.

Coming from a history of science perspective, Kuhn described the enterprise of science as composed of two distinct phases, a "normal" phase where the problems pertinent to the central theory are solved and is like "filling in the puzzle" of the theory. He called the other phase of science, "revolutionary" because, during this phase the structure of concepts, facts, instruments of inquiry and even social relations between the scientists involved in the particular research community are disrupted by a competing theory with the entailments a new gestalt brings. This new theory may gain ascendancy based on many factors, especially if it can more satisfyingly solve important problems that were intractable with the previous theory. Kuhn famously named the assemblage of facts, laws, problems of interest, instruments of investigation and social relations within that community of investigators organized around a central theory, as composing a "paradigm". Kuhn asserted that this new theory—the one causing the revolution—was not simply an improved version of the old theory, but that each theory really described a different reality. Kuhn invoked Hanson's Gestalt switches to explain this new way of

looking at an unchanged reality: "The conversion experience that I have likened to a Gestalt switch remains, therefore, at the heart of the revolutionary process" (1970, p. 204). Gestalt theory explains the concept that observation is theory laden. Section 2.2.3 connects the ideas of Gestalt and a classroom of students engaged in KB discourse: class wide Knowledge Building activity is itself a Gestalt, an emergent of this goal-oriented activity. Section 4.2.3 provides further development of the idea of Gestalt and its connection to one of the central ideas of this research: design mode engagement.

In his second edition of his landmark book, *The Structure of Scientific Revolutions* (1970), Kuhn made explicit that scientific theories are not ever-closer approximations of reality, just different interpretations of sensory data affording the capabilities to solve more problems and also discover new problems. In this, both Kuhn and Hanson argued against the correspondence view of knowledge shared by Popper and others that claims a direct albeit fuzzy connection between reality and knowledge. They asserted that solving problems is not simply a critical process creating ever-closer approximations of reality but is instead an imaginative process, kept in check by critical processes. In other words, Hanson and Kuhn would be fine with Popper's process of scientific problem solving that involved conjecturing a tentative solution, eliminating errors with critical processes and creating a reliable solution. Kuhn would also agree that viewing the world through that newly created idea would create a new set of problems. However, Hanson and Kuhn would view the problem more like Dewey envisioned it, of "…convert[ing] the elements of the original situation into a unified whole" (Dewey,

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1938, p. 105). In conclusion, Kuhn saw scientific inquiry as problem-solving embedded within a specific community of scientists, taking into account its methods, tools, organizing theories, problems of interest and social relationships within the community. While it is not uncommon for observers of Kuhn's ideas to note the similarity between paradigm shifts and Gestalt switches, Kuhn only acknowledges it tentatively: "*Nevertheless, the switch of gestalt, particularly because it is today so familiar, is a useful elementary prototype for what occurs in full-scale paradigm shift.*" (1970, p. 85).

Viewing science as problem solving, that scientists work to solve research problems to create knowledge, is not just the perspective of philosophers and historians of science or of researchers of science education. Indeed, the idea that science is about addressing problems within a community is also prevalent for working scientists(Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003).

2.2 Science: the iterative improvement of knowledge

As established in section 2.1, viewing science as a form of problem solving is common in the philosophy of science. Furthermore, it is common that working scientists speak of research problems being interrogated with research questions, perhaps an indication of these ideas as helpful in actual science. Although seeing science as problem-solving is common, there are diverse understandings of problems and problem-solving, and as described by Kuhn, these are "coordinated" with the other elements of a person's Gestalt to create the integrated whole. For example, Popper's idea of problem-solving as represented in his tetradic schema: Problem → Tentative Solution → Error Elimination

→ New Problem (see Figure 2.1) was part of his solution to the demarcation problem

after having replaced the inductionist view with falsification, all part of what he calls,

"critical rationalism". The three-world ontology allowed Popper to disconnect knowledge

and "knowers", useful for his critical rationalism. In contrast, Popper's ontology has been

borrowed and repurposed as a tool to develop an approach to education to meet the

demands of the knowledge age (Bereiter & Scardamalia, 2006). Popper saw problem-

solving as a logical process of eliminating errors from theories or solutions. While

Bereiter acknowledges that critical evaluation is an essential part of theory improvement,

he applied the three-world ontology to develop an epistemology and pedagogy focused

on the creative improvement of theory, an approach not well known in the United States

and elsewhere. Section 2.2 will develop the ideas from section 2.1, providing further

foundations permitting section 2.3 to answer research questions one and two. That is, 2.3

will show how knowledge improvement, when considered from a problem-solving view,

can be represented with a simple visual model. This model is then extended to permit

visualization of the iterative and branching aspects of solving problems in a community.

2.2.1 Knowledge building explains scientific problem solving

Concerned not with demarcation and ideas of falsification but with designing an

approach to education consistent with the primary activity of the knowledge age: the

continuous innovating of solutions to problems, Scardamalia and Bereiter (1993) applied

Popper's idea of W3 in a different way. They developed the idea of W3 as not just a

place inhabited by cultural artifacts, but as a collaborative workspace where knowledge is

created and improved, that is, where knowledge is built. While Popper used the three-

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world ontology to explicate his conception of science, Bereiter and Scardamalia used it to effectively describe what they call, Knowledge Building epistemology. The term Knowledge Building can refer to three different concepts that hold together in a comprehensive paradigm of education: an epistemology, a pedagogy and a type of activity. Section 2.4 seeks to provide both a foundation and overview of this paradigm.

The problem Bereiter and Scardamalia sought to solve was the fundamental mismatch between 1) the competencies needed for the knowledge age where innovation is the golden principle and 2) the current education systems where student activity is not organized around the practices of innovation but instead around developing critical thinking, aiming for students to be "careful, rigorous thinkers" (D. Kuhn, 1999, p. 16). They do not discount the essential importance of critical thinking but instead insist that critical thinking should be contextualized in its role in the work of innovation. They developed a term, "design mode", to describe an approach that complements the analytical, that is critical, approach. This concept of "design mode" is described in the following paragraphs and will be extensively developed throughout this research. Knowledge building. Education aiming at developing the competencies required in routine activities in the knowledge age are often described as, "21st century" [describe some of these competencies from both the business and 21st century education literature]. Scardamalia & Bereiter (2006b) explained the need for an approach centered around building the capacity to innovate knowledge:

> *"Sustained knowledge advancement is seen as essential for social progress of all kinds and for the solution of societal problems. From this standpoint the*

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fundamental task of education is to enculturate youth into this knowledge-creating civilization and to help them find a place in it (p. 98)."

The approach they developed to solve the discrepancy between education's current focus on critical thinking and one that encultures youth in an innovation-centered society is called "Knowledge building" (KB). This approach is founded in an epistemology based on Popper's three-world ontology and specifically leveraging W3. The essence of their approach is it aim: developing an approach to education where student communities (classes) engage in progressive knowledge-problem-solving as exemplified by scientific communities.

The term, "Knowledge Building" is commonly assumed to describe learning, likely due to the similarity of its name to the educational term, constructivism. Constructivism considers learning to involve building knowledge on to one's existing knowledge structures. However, Knowledge Building is associated and indeed modeled after the type of productive knowledge-innovation work in which communities of scientists are constantly discovering and solving knowledge problems as they work to improve the theories of their field. Therefore, Knowledge Building shares the aim of science: the development of a community's reliable and comprehensive theories. An apparent contradiction due to modeling a classroom community upon a science community is that education and science do not have the same mission. The aim of a community of scientists is to advance their field's shared theories and problems while the mission of a community of students is learning, that is, the growth of individuals and communities. This apparent contradiction of aims is resolved in two stages. First, while

students' central aim during Knowledge Building is to create public knowledge, that is, enrich the class' W3 space, learning is a valued byproduct of this problem-solving process (Scardamalia & Bereiter, 2006b). Second, problem-centered learning, the type of learning that happens during inquiry, produces typically more useful knowledge than referent-centered-learning, that is, the learning that happens when studying information organized by a discipline's logical classification (Bereiter, 1992). Knowledge Building can be described as an approach to education where students learn the competencies needed for the knowledge age and in the process constructively learn conceptual knowledge. Therefore, a challenge in the development of this approach is to develop strategies to achieve learning aims as one works towards overarching knowledge advancement aims. Research questions one and two work towards addressing this latter challenge.

An important concept entered into KB literature in 2003. This concept developed to explain why KB sometimes "worked" and other times did not and thereby identified essential elements of Knowledge Building pedagogy. Bereiter and Scardamalia (2003) identified the "mode" of activity as significant. This concept labeled, "design mode" was articulated by contrasting it to "belief mode". Bereiter argued that design mode is the primary mode of activity in all creative disciplines while "belief mode" is the primary mode in schooling. "Belief mode is so called because its concern is to arrive at true or warranted beliefs" (Scardamalia & Bereiter, 2006a, p. 13). This focus in school can be sensibly explained: we want students to learn correct grammar, actual history, accurate

science, correct math. Ideally, this "belief mode" engagement is through excellent critical

engagement such as the argumentation practices described in the NGSS (NGSS Lead

States, 2013):

> *"All ideas in science are evaluated against alternative explanations and compared with evidence, acceptance of an explanation is ultimately an assessment of what data are reliable and relevant and a decision about which explanation is the most satisfactory. Thus knowing why the wrong answer is wrong can help secure a deeper and stronger understanding of why the right answer is right. Engaging in argumentation from evidence about an explanation supports students' understanding of the reasons and empirical evidence for that explanation, demonstrating that science is a body of knowledge rooted in evidence" (p. 42).*

In order to avoid confusion associated with the use of the term belief mode, Bereiter and

Scardamalia have recently chosen to use, "critical thinking" in its place.

Describing what they mean by "design mode", Scardamalia and Bereiter (2006a)

explain:

> *"In design mode, the concern is not with ideas as objects of belief but with ideas as objects of creation, development, assembly into larger wholes, and application. Instead of being judged for its truth claims, an idea is judged according to how well it serves its purpose and on its potential for further development, for leading somewhere desirable" (p. 14).*

Bereiter and Scardamalia (2006a) regularly distinguish design mode activity by the types

of "objects" produced in this mode and their use, saying that the:

> *"products may be scholarly things like theories, histories, and proofs or more practical things like designs, inventions, and plans. The common element is that these products constitute new or improved ideas that the community can use in producing more new or improved ideas" (p. 4).*

As the overall epistemic aim of design mode work is the solving of authentic, "felt" problems as extensively described by Dewey, the solution is typically interrogated with question such as, "What is this idea good for? What does it do and failed to do? How could it be improved?" (Bereiter & Scardamalia, 2003, p. 4). Design mode work is characterized by a term that has become central in the business world's discussion of creative and innovative enterprises: design thinking (Bereiter & Scardamalia, 2014, p. 39). This term will be discussed further in section 4.2.3.1

At its most basic, Knowledge Building activity is the extended, collaborative and iterative improvement of ideas. Knowledge building epistemology considers the products of science: theories, questions, problems, solutions, models, procedures, methods and methodologies, etc. to be objects in a W3 sense, and thus are referred to as "knowledge objects" or KO for short. Knowledge work could then be described as work where KO's are iteratively improved. In conclusion, Bereiter extended Popper's idea of W3 in a direction that perhaps Popper did not explore, that of conceptualizing W3, in conjunction with W1 and W2, as a workspace for knowledge work, as a place where knowledge is innovated. Considering KO's, as improvable objects, that is, objects amenable to design mode work invokes considering KOs as designed object. This is the accepted view in engineering where a prototype is considered a material embodiment of an abstract model that is, a KO. Said in another way, in engineering the abstract W3 models are developed, and when they are ready for real-world testing the prototype is created: a W1 embodiment of a W3 object. When the W3 model being iteratively developed has met the

design criteria, it is embodied again in a physical object, the final product. Of course,

these conceptual models can be continually improved, the automotive industry having

done this for over one hundred years. Distinguishing between the W3 KO's and their W1

embodiments or expressions is also the accepted view in US patents where the thing that

is patented is not the physical object, but instead its abstract structure. Perkins (1986)

develops this idea further, explaining how all knowledge can be considered as KO's, not

just the product of engineering. This thesis is developed in the following section.

2.2.2 Perkins: Viewing knowledge as a designed object

An educational researcher, Perkins inquired into learning and deep understanding

and the associated nature of knowledge. He argued that we ought to view knowledge not

as information but as design. He developed this concept in the context of education

showing that it had significant implications on how we teach and learn. Perkins (1986)

defined a design as "a structure adapted to a purpose" (p. 2). For example, Perkins uses

the idea of "question", or perhaps it would be better described that this example looks at

the idea that we label with the word, "question". The idea identified by the word,

"question" has a structure (a definition), for example: "a sentence worded or expressed so

as to elicit information." We can say that this word, "question" is adapted to the purpose

of identifying a way that information is obtained. In other words, we will use one of these

things, a "question", when we wish to come to know an unknown. For the second

example, a model of inquiry, the interrogative model of inquiry developed by Hintikka

(1981). This model proposes is an intention-driven method by which one can come to

understand nature. The conceptual structure of this model of inquiry can be adapted to the

purpose of explaining how we are able to come to know the unknown. Even a specific

phone number can be considered as a design, a structure adapted to a purpose. Though

not often improved, the design of a phone number can be changed. For example, the first

area code was added onto a person's phone number in New York City in 1947. An

extensively elaborated theory such as the theory of evolution can also be considered as a

design, its structure adapted to the purpose of, for example, explaining and predicting and

identifying phenomena related to the changing frequencies of alleles (and their resulting

traits) over successive generations. And in this sense, any specific KO, a specific

problem, question, theory, law, fact, paradigm, etc. existing in W3, a shared cultural

knowledge-object space, can be considered a design: a structure adapted to a purpose.

And, while all of these KO's are improvable, some objects have more potential for

improvement than others.

2.2.2.1 Combining Knowledge-as-design and World 3 clarifies KB

The following paragraphs develop a synthesis of Perkins conception of

knowledge as design and Bereiter and Scardamalia's interpretation of W3 as the abstract

world of knowledge work. This synthesis is designed to extend the concept of design

mode work in the context of Knowledge Building. Perkins emphasized that knowledge is

designed for a purpose. This conception is well known in engineering. Typically,

engineers solve "problems of doing", that is, solve the problem where one needs to

accomplish a situation-specific goal and no adequate solution exists. They engage in

engineering practices, developing a solution through both creative and critical processes

until a model, i.e. design, has been developed that solves the practical problem, meeting the design criteria. Because of the specific nature of the problem solved, engineers' solutions can be described as context specific designs. Science solves a different domain of problems yet its solutions are also understood to be designs: structures adapted to a purpose.

As elaborated in section 2.1 and 2.2.1, considering science as problem solving is common. One problem Newton sought to solve was the "problem of explaining" how force, mass and the resulting acceleration are related. The solution he created is labeled, "Newton's second law of motion". This too can be considered a design: it is a structure made of related parts as represented in this equation: $F = mA$, and is adapted to a purpose, the purpose of explaining almost any kind of (non-relativistic) motion problem given to it. A defining characteristic of solutions to science problems is their broad range of applications, that is, the designs of the KOs produced by scientists are context general. Indeed, solutions that can explain more phenomena are more highly valued by scientists.

Because of the sciences' unending pursuit of deeper and broader solutions, science can be described as progressive problem-solving. The problems addressed by science are expected to continually transform to connected and deeper problems. This indefinitely unfolding characteristic of science inquiry sets Knowledge Building apart from other successful design-based approaches to education such as Fostering Communities of Learners and Learning by Design, both which use engineering problem-solving to learn science. This progressive transformation of science problems and the

resultant deepening of the theory also provides a way to distinguish the unique characteristic of the inquiry that is Knowledge Building from the inquiry expected from science standards. This progressive inquiry where students identify and solve progressively deeper science problems is the aim of KB though not of the standards. Interestingly, the science vignette provided at the start of Chapter 1 was used as an exemplar of inquiry in the NSES (National Research Council, 2000). It is hoped by this author that KB can help reclaim that progressive aspect of scientific inquiry for science education.

2.2.3 Knowledge building as an emergence

A systems theory approach is useful to understand Knowledge Building. It is not uncommon to see systems theory included in the analysis and discussion of Knowledge Building [cite a few]. The study of complex systems or complexity study "can be defined as the study of the emergence and self-organization of networks of interacting agents" (Demerath & Suarez, 2019, p. 224). A complex system is said to exhibit synergy, sometimes expressed as the whole being more than the sum of the parts. Well studied examples of complex systems include neural networks made of neurons, living organisms made of cells, businesses made of individual "agents" (humans) and ant colonies composed of agents, i.e., ants. In these examples one cannot predict the properties of the whole based on an examination of the individual parts. The term "emergence", central to complexity studies, can be thought of as those properties and behaviors of the whole that cannot be explained based on knowledge of individual parts.

The idea of emergence was presented in section 2.1.3 where Hanson (1958) used images from the Gestalt school of psychology to illustrate that the meaning we make from visual inputs is more than what was provided by the visual stimuli. Images such as the, "old Parisian woman" where one can alternatively but not simultaneously see a young woman or an old woman (Hanson, 1958, p. 11) exemplify this. As presented in section 4.2.3, Edwards draws a connection between engaging with visual inputs as a Gestalt and the cognitive mode characteristic of artistic creativity. Extending this idea of Gestalts' role in creative process beyond the visual realm, Hanson argued that Gestalts are more than just a visual cognitive phenomenon. He argued that understanding is constituted together with observation as a Gestalt, in other words this Gestalt is an emergence. In this sense, understanding is a creative emergent, and it is suggested that this creative cognitive mode described by Edwards is connected to the design mode engagement described by Bereiter and Scardamalia introduced in section 2.2.1. Complexity studies consider the emergent properties and behaviors of the complex system as the unit of analysis, in contrast to reductionism which aims to explain systems in terms of the parts and their interactions. Put in another way, complex studies aim to capture complexity in their models rather than reducing the complexity in order to explain the system.

A central topic in complexity study is the concept of self-organizing networks: the process where initially unorganized parts spontaneously organize simply due to local interactions between the parts, thereby giving rise to a complex system having emergent

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properties and behaviors. Wagemans et al. (2012) explain Gestalts in terms of self-organization, that "Gestalts emerge spontaneously from self-organizational processes in the brain" (p. 1219). Knowledge building communities are conceptualized in terms of self-organizing agents instead of hierarchically-organized elements. Knowledge building communities are considered to be composed of individual agents, or more precisely, individuals with their own epistemic agency, interacting peer-to-peer both physically yet also over a class-wide network, through epistemic discussions around shared problems of explanation. Through these epistemic actions embodied in students' KB participation, an idea-network emerges as a Gestalt. Knowledge creating communities can be analyzed as self-organizing systems on different levels, from the individual cognitive level up through the social cultural level and up to the epistemic level. It is this epistemic self-organizing level where it is "ideas themselves that interact to form more complex ideas" (Scardamalia & Bereiter, 2010, p. 12). Conceptually speaking, this epistemic self-organization can be said to occur in the student-developed W3. Because of this emergent nature, assessing casual patterns in KB activity is extremely difficult. As described by Stahl (2006), assessing knowledge creation through studying written contribution is problematic due to the fact that knowledge creation is an emergent of the whole communication and activity system. Instead of trying to track the epistemic sequential development of the network of contributions and threads from which the knowledge improvement emerged, a more basic aim of descriptive theory and method of a hybrid

philosophical – empirical method of coding individual contributions was developed. This is presented in Chapter 4.

2.2.3.1 Knowledge building principles support self-organization on three levels

Based on a decade of effort supporting the transformation of classrooms into a KB communities, Scardamalia (2002) developed a list of 12 Principles considered essential for the success of KB (Table 2.1). This set of principles is considered the highest level of scaffolding for the international community centered around Knowledge Building. These principles guide research, technology development, pedagogy and student intentionality in order to facilitate classroom communities to self-organize such that knowledge creation and learning are significant emergents. These 12 principles therefore serve to guide teacher professional development, evaluate existing practices and for technology design specification (Scardamalia & Bereiter, 2010). These principles are seen to be flexible enough for instantiating KB classrooms in different cultural contexts (So, Tan, & Tay, 2010).

Table 2.1 Twelve principles of Knowledge Building (Scardamalia, 2002).

Principle	Detail
1 Real ideas and authentic problems	In the classroom as a Knowledge building community, learners are concerned with understanding, based on their real problems in the real world
2 Improvable ideas	Students' ideas are regarded as improvable objects
3 Idea diversity	In the classroom, the diversity of ideas raised by students is necessary
4 Rise above	Through a sustained improvement of ideas and understanding, students create higher level concepts
5 Epistemic agency	Students themselves find their way in order to advance
6 Community knowledge, collective responsibility	Students' contribution to improving their collective knowledge in the classroom is the primary purpose of the Knowledge building classroom
7 Democratizing knowledge	All individuals are invited to contribute to the knowledge advancement in the classroom
8 Symmetric knowledge advancement	A goal for Knowledge building communities is to have individuals and organizations actively working to provide a reciprocal advance of their knowledge
9 Pervasive Knowledge building	Students contribute to collective Knowledge building
10 Constructive uses of authoritative sources	All members, including the teacher, sustain inquiry as a natural approach to support their understanding.
11 Knowledge building discourse	Students are engaged in discourse to share with each other, and to improve the knowledge advancement in the classroom
12 Concurrent, embedded, and transformative assessment	Students take a global view of their understanding, then decide how to approach their assessments. They create and engage in assessments in a variety of ways

Interestingly, all of these principles, which aim to facilitate and augment the

knowledge creation emergents of the classroom community also facilitate the emergence

of learning both on a cognitive and socio-cultural systems level. For example, the

principle, "epistemic agency" acknowledges the primary importance of students taking

the lead as knowledge creators. A strong sense of epistemic agency is an essential

characteristic of members of any epistemic community; indeed, it is hard to imagine how

a research community could survive much less thrive if the researchers (the agents in that system) did not feel it were within their power to improve their fields knowledge. Connected with the idea of epistemic agency is the principle (6) "Community knowledge, collective responsibility". This principle aims to ensure that members in the community both have a sense of ownership of the knowledge being developed as well as share a sense of responsibility that it is their mission, their collective responsibility, to advance the frontiers of this communal knowledge. Both of these principles aim to empower knowledge creation by the community as well as ensure that all Knowledge Building members of that community learn. Said in another way, all students in the class would need to internalize the emerging KO's in their own knowledge systems as only in this way could members grow as epistemic agents. It is not trivial to note that this internalization process occurs through knowledge problem-solving, a deeply constructivist process [cite Dewey, Scardamalia and Bereiter, including article on referent versus problem centered knowledge]. All communities that are part of the Knowledge Building education ecosystem: researchers, technology developers, teachers and the students themselves, ideally avail these 12 principles based on their own role in the overall system.

2.2.3.2 Software supporting epistemic self-organization

Collaborative software is considered an essential part of a pedagogical system in the Knowledge Building approach. It provides a shared space that, "literally adds a new dimension to conversation, a dimension embracing symbolic representation,

manipulation, and memory. ... It takes shared space to create shared understandings"
(Schrage, 1995, p. 94).

Information technology systems afford supportive and, in some cases, essential
functions for Knowledge Building classroom communities. To understand the
fundamental need of this software it is necessary to distinguish between Knowledge
Building which is the *sustained*, student led and enacted, iterative transformation of
problems of understanding with inquiries that last a day or two, or with rich,
transformational class discussions. While these last two activities are excellent elements
of a classroom seeking to realize Knowledge Building, without the kinds of scaffolding
provided by KB software environments, the weeks-long, student-directed progressive
problem-solving cannot occur. Schools are not structured to facilitate knowledge creation
by the students and several problems need to be solved for Knowledge Building systems
to develop in the classroom.

In addition to the two instructional strategies given above, other non-computer
supported communication and inquiry strategies are essential to building knowledge such
as whole class and small group idea-centered and problem-centered discussions. Another
strategy "Knowledge Building circles" provide an opportunity for everyone to share and
build on each other's ideas, sharing values, opinions and feelings with the whole class.
This process can be effective in rapidly developing a problem area, exchanging and
exploring a wide diversity of ideas quickly. Furthermore, these discussions provide the

opportunity for positive relational development in the classroom. The strategies listed

above however lack several key affordances required of complex KB systems.

The feature that makes discussion circles an important classroom strategy for

Knowledge Building, that only one person at a time talks, is exactly the same reason why

whole group oral discussions are insufficient for Knowledge Building discourse. The

linear flow of ideas afforded by turn-taking discourse does not support the development

of a complex system of idea interaction. Neither do interactional structures such as think-

pair-share, jigsaw, fishbowl or think-aloud pair discussions. Not only is there no

permanence of KO's developed in oral dialog, there are no affordances for the growing

dozens of discrete knowledge objects to be independently reflected upon and built upon

over time. The one-to-many discourse structure needs to be bolstered with a many-to-

many discourse structure. A networked database with multiple inputs such as computers

or phones affords this capability (Scardamalia & Bereiter, 1993). In conclusion, this

software removes the teacher, or more generally any one person, as the bottleneck of

communication, allowing multiple class-wide conversations to happen simultaneously

(Scardamalia & Bereiter, 2006b). As expressed by Stahl (2006) about the need for KB

software such as the original CSILE:

> *Before we had systems such as CSILE, collaboration across a classroom was*
> *not feasible. How could all the students simultaneously communicate their ideas*
> *in a way to which others could respond whenever they had the time and*
> *inclination? How could all those ideas be captured for future reflection,*
> *refinement and reorganization? (p. 262)*

A further problem requiring networked information technology is due to the

extended time periods, weeks or months, over which the progressive transformation of

knowledge problems takes place. Knowledge building discourse is expected to progress through repeated cycles of inquiry, branching along the way. While some inquiry-branches become abandoned, ideas advancing on other branches or multiple branches can be recombined and the epistemic progress summarized, yet at once revealing deeper problems, inviting new research agendas. The developing network of student contributions reflects the state classes knowledge advancement and is a system of knowledge objects important for class and individual reflection on their knowledge advancement and as a source of possibly promising ideas available for development. This requires that the complex network of interacting KO does not overtax the Knowledge Building agents' cognitive load, an expandable digital space and is accessible on demand throughout the extended inquiry. It should be noted however that in elementary settings where there is only one class of students per classroom, displaying a community's unfolding KB discourse on the classroom wall is feasible. An excellent example of this was provided in the vignette of the fifth-grade classroom at the start of chapter 1.

Knowledge building environments (KBE's), such as the Computer Supported Intentional Learning Environments (CSILE) (later named, "Knowledge Forum" (KF)) from the University of Toronto and Future Learning Environment (FLE) from the University of Helsinki, were designed to afford the necessary supports so that a classroom community of novice knowledge builders could successfully instantiate a knowledge creating community. The design of many of the features in each KBE were based on knowledge creation theories (Hewitt & Scardamalia, 1998; Muukkonen,

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Hakkarainen, & Lakkala, 1999; Muukkonen, Hakkarainen, Lipponen, & Leinonen,

1999). For example, FLE "embodies a model of progressive inquiry development"

(Muukkonen, Hakkarainen, & Lakkala, 1999) while Knowledge Forum was tightly

aligned with the 12 principles after they were developed in 2002 (Scardamalia, 2002).

Chen and Hong (2016) note the important role technology serves in, "…turning epistemic

agency over to students". Taken together, the features of a KBE can enhance the

capability of a classroom of students to engage in such a way as to increase their

likelihood of continually self-organizing as a knowledge creating community. Figure 2.2

presents a screenshot of a knowledge building discussion in a 2018 version of Knowledge
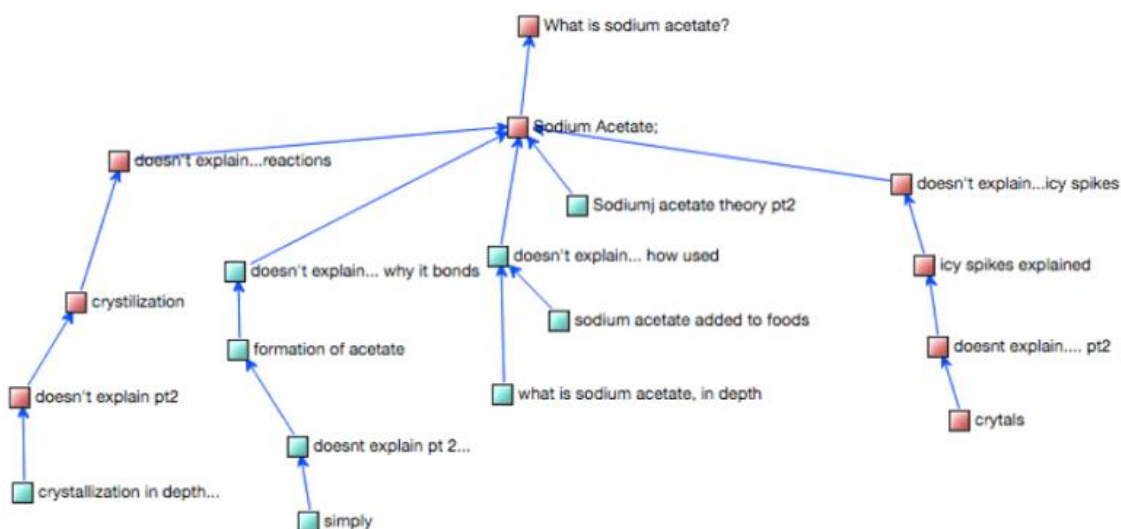
Forum.

Figure 2.2 Screen shot showing a KB discussion from a 2018 version of Knowledge Forum software.

2.2.4 Channeling agents' "local" interactions to align with expert practices

To help novice knowledge builders succeed, Knowledge Building environments need to provide various types of support. The KBE needs to have features such as: expandable digital space that provides permits discourse to unfold without limits, visual cues indicating the order of comments in a thread and visual organizing strategies to reduce users cognitive load. Taken together they increase the likelihood of the tool or set of tools to be used in such a way that creates a complex system where knowledge creating emerges. Another type of support required of the KBE is to guide agents when working in their "Zone of Proximal Development" (Vygotsky, 1978) that is, beyond that permitted by their current independent level of expertise (Scardamalia & Bereiter, 2006b). Without this scaffolding, it is unlikely that many novice knowledge builders will be able to "move beyond simple question-answer discussion and elicit practices of progressive inquiry" (Muukkonen, Hakkarainen, & Lakkala, 1999, p. 5). Conceptualized in a flexible manner (Schank, 1999), as part of one's schema, internal scripts help people understand and act in the world. In situations when the internal scripts are missing or inadequate such as when a novice knowledge builder engages in epistemic, collaborative activity through the computer, software features can provide "external scripts" to scaffold that "more expert" participation. This technological scaffolding is considered analogous to Vygotsky's social scaffolding. Active use of external scripts have been shown to shape internal collaboration scripts of the KB participants, that is not only do they support actors' performance but also help them learn how to succeed with it independently (Fischer, Kollar, Stegmann, & Wecker, 2013).

Table 2.2 The Five Knowledge-types supplied by FLE4 to scaffold student KB participation.	
Knowledge type	**Description**
Question/Problem	Used to present a problem or interrogate
My Explanation	Used to present one's own intuitive ideas. No claim to authority is made
Source-based Explanation	Used to present information considered authoritative. Source should be given.
Process comment	Used to note concerns with or ideas for the classroom dialogue itself.
Summary	Used to present a summary of a discussion.

Both KBE's have affordances that serve as a heuristic to guide the actor to engage in the discourse effectively. These affordances can be considered as external scripts as they bolster the insufficient internal scripts. This scripting is realized differently in each environment. Of the two designs, the design of FLE provided stronger guidance and will be described here. When ready to respond to a class mate's contribution an actor clicks on the reply button and an empty contribution window opens up. At that point a student can just start typing into the body text field. At any point the knowledge builder can refer to the prompts at the top of the window that briefly describe the five types of contributions to be made. These five Knowledge Types are given in Table 2.2. In order for the "Post" button to be activated, the agent needed to select one of these five "knowledge types" (KT's) from a drop-down list that corresponds to the epistemic aim of her contribution, shown in Figure 2.3. Each knowledge type has an assigned color, visually communicating the epistemic aim of the contributions. The set of knowledge

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types are considered to be a complete set, the full set of epistemic moves required to

build knowledge, that is to, develop theory.

Figure 2.3 Screen shot from FLE illustrating selection of contributions knowledge type

     This scripting depended on students being able to make each of the five epistemic

moves independently, by reviewing the choices students are constantly being reminded

that these five types of moves compose Knowledge Building discourse. By reviewing the

brief description of each knowledge type when needed, the agent was repeatedly

provided with the opportunity to distinguish and internalize the characteristics of each of these knowledge types. There are problems with this categorization of epistemic moves that will be described further in chapter 3. Nonetheless the system of scaffolds supported students by channeling their contributions and thereby creating a higher quality complex system of connected epistemic moves. Having a higher percentage of effective epistemic interactions and knowledge objects means the unfolding state of knowledge of the community embodies greater knowledge advancement.

A paradox can be said to have occurred, however. Positing that a class had successfully advanced a theoretical explanation of some phenomenon and that channeling an agents' engagement by the scripts served a significant role, it can be said that the knowledge building agent learned about the phenomenon and its explanation as well as further internalized the specific Knowledge Building moves facilitated by the scripts used. However, it would be unlikely that the agent would be better at explaining what knowledge improvement was beyond describing what they had done and learned and perhaps also that KB involves specific epistemic moves. This is a characteristic of complex systems: agents are only aware of their local context, such as meeting an inadequate explanation with a description of its weakness. This problem could be described as not seeing the forest for the trees. Through participation in KB supported by scripts, agents do gain more detailed knowledge of the five different KT's but do not gain a model of knowledge improvement beyond knowing that it involved an interaction of these five KT's. In other words, the type of response to the question, "So, what is

Knowledge Building?" would be a comment about the activities performed: participation does not provide a higher-level understanding. This is a problem when an agent attempts to analyze what might be the best epistemic move in a particular situation or explain to someone else why they thought the state of knowledge of the class required some particular type of epistemic action. Furthermore, while the agent would grow in confidence in her ability to engage in Knowledge Building, she likely would not gain the sense of satisfaction that comes with being able to succinctly explain what Knowledge Building is. While extensive experience with these five guiding knowledge types would internalize the moves needed for knowledge building and they could be enacted with automaticity, it would be a struggle to reflect on and analyze the class' and their own knowledge building because of the lack of a simple model explaining the knowledge building process.

The lack of a simple model explaining knowledge improvement is most severely felt by the teacher. The teacher needs a model with which to solve the dozens of instructional "problems" due to her multiple and changing roles in the complex Knowledge Building system, both during student-contact time as well as non-student contact time. In other words, the problem was one of not having a simple conceptual model to understand the process of knowledge building, and the limits this placed on students and teacher's ability to reflect, analyze and strategize in their knowledge building practices. This was the first problem addressed in this research and resulted in the creation of a heuristic useful to both students and teachers for understanding the

process of building knowledge. This heuristic is based on the literature reviewed in this chapter and is described in section 2.3.

A further essential function of knowledge building software is its ability to scaffold agents to think through more complex ideas due to the software representing information in a consistently accessible location referred to as an external memory field or EXMF (Donald, 1991; Hakkarainen, 2009; Ritella & Hakkarainen, 2012). External memory fields extend our working memory allowing us to solve more complex problems. Furthermore,

> *Externalization produces a record of our mental efforts, one that is 'outside us' rather than vaguely 'in memory'. ... It relieves us in some measure from the always difficult task of 'thinking about our own thoughts' while often accomplishing the same end. It embodies our thoughts and intentions in a form more accessible to reflective efforts."* (Bruner, 1996, p. 23)

2.3 Making Knowledge Building more accessible

A limitation of the KB approach is that it does not have a simple description of how the different epistemic moves implied in the knowledge types used in the KBE's scaffolding interact to advance theory. While agents productively engage in KB discourse through specific epistemic moves with other agents in the KB community and knowledge advancement emerges at the community level, it is difficult not only for the agents, but for leaders of the community such as the teacher to reduce the agents' productive interactions to a model useful for understanding and leading the community, i.e., the class. In other words, the lack of a pedagogical model is a problem for the teacher because without it, a teacher has a hard time designing units of study, lesson sequences, lessons and activities to make practical the sustaining of ever deepening inquiry. If a

teacher only had one or two classes only taking up a total of two or three hours in a day a much more emergent approach to teaching would be possible, but with five different groups of students, 25 or 30 in a class, five hours of class time, five days a week, greater structure is needed to make Knowledge Building a practical reality.

2.3.1 Progressive Inquiry: making Knowledge Building, doable

A team of researchers led by Hakkarainen (2003) created a solution to the need of a pedagogical model to support teachers' instantiation of KB in their classrooms. This model, progressive inquiry was important to me as I developed and taught the evolution unit. The theoretical foundation for progressive inquiry come from two sources: Bereiter and Scardamalia's Knowledge Building and Hintikka's Interrogative Model of Inquiry (Muukkonen, Hakkarainen, & Lakkala, 1999)

Hintikka's Interrogative Model of Inquiry envisions scientific inquiry as a discourse, so to say, between the inquirer and Nature: the inquirer posing questions and nature 'answering' them. Specifically, the inquirer asks a big "why" question of nature, however often too big to be figured out in a single exchange. The inquiry advances by breaking apart the initial big question to smaller, answerable questions, often referred to as "Wh…" questions including "What…" questions which including testable questions, and Who…, Where… and Which… questions. The inquiry proceeds as one gains answers to these smaller questions and then puts this knowledge back together to provide a full answer to the original big question. This view sees inquiry as a relatively simple back-and-forth process of questions and answers. Furthermore, Sintonen (1993) argued that a problem-solving agent must propose working theories and questions before the

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problem itself is well understood. It is through these working theories that necessary questions are posed and the working theory transformed to a more sophisticated one.

Progressive Inquiry afforded among other possibilities two advances described here: a pedagogical model of knowledge creation and a refinement for the software scaffolding in a KBE. The Progressive Inquiry (PI) model as represented in Figure 2.4 illustrates that knowledge creation in a classroom can be considered a flexible progression of stages. 'Creating the Context' can be considered 'exploring nature' while the 'Setting up Research Questions' stage can be considered asking big, theoretical, questions of nature. The 'Constructing Working Theories' has students creating their best (intuitive) theories or explanations to answer the big, typically "Why…", questions. The 'Critical Evaluation' stage is where students problematize their intuitive theories breaking down the initial big questions into smaller questions that search for reliable, typically source-based information. In the 'Searching Deepening Knowledge' phase students search for answers to these smaller questions and continue to answer and question through the next phase, 'Generating Subordinate Questions'. Finally, during the 'Refocusing the Inquiry Process' the community assess the state of their knowledge and seeing how their current theory satisfies their original big question. At this point a new iteration of the process may continue with newer and deeper or related questions. In conclusion, the progressive inquiry model brings a punctuated, processual view to Knowledge Building. Furthermore, it uses an intuitive, question answer dynamic to

inquiry. These conceptions simplify Knowledge Building, making it more manageable

for teachers as well as students.
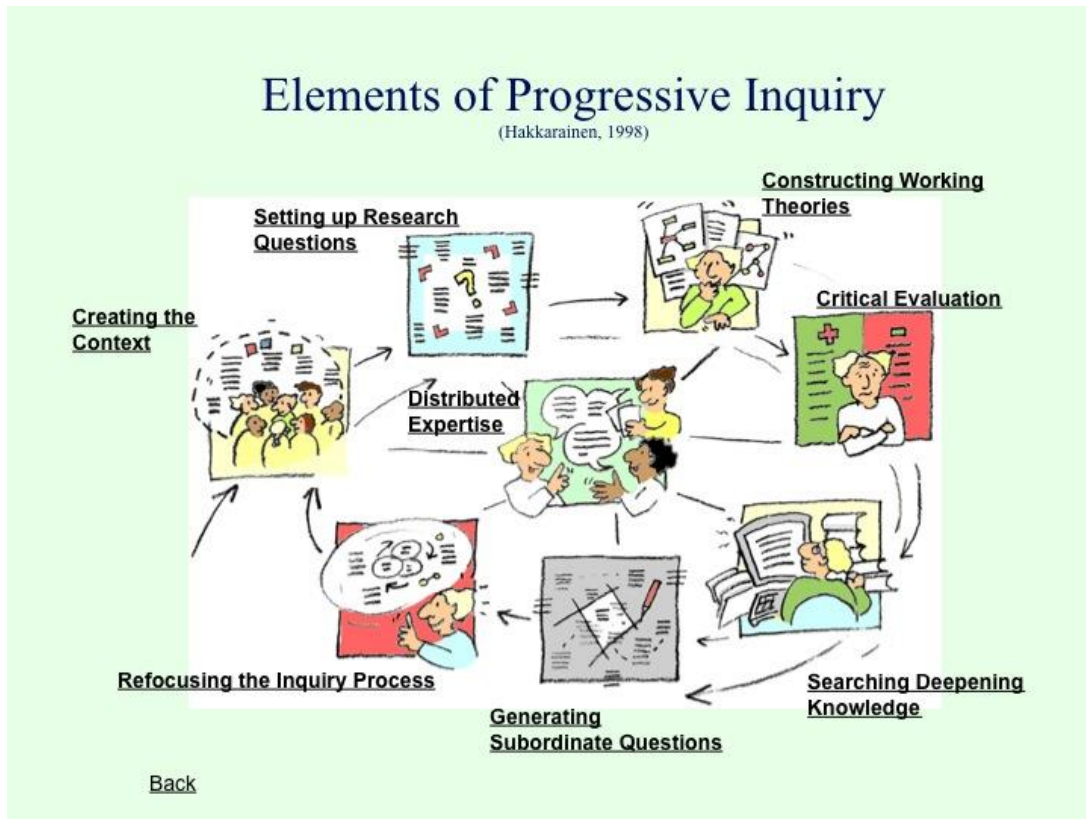
Figure 2.4 Hakkarainen (1998) represents progressive inquiry as spiral iteration

The second advancement was in the scaffolding of Knowledge Building discourse

in their KBE. The scaffolding was described in section 2.2.4, described as the

strengthened scaffolding of epistemic moves provided by FLE. These improvements are

afforded by the interrogative models which conceptualized inquiry, knowledge problem-

solving, as a back-and-forth questioning-answering dynamic. This generalization worked

well with Popper's W3 concept of knowledge objects. Combining these two ideas

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afforded the simplification that Knowledge Building dialogue can be reduced to the

interplay of two basic types of knowledge objects: questions and answers. Therefore, the

KB dialogue can be simplified or clarified as a system of contributions, each contribution

being a specific epistemic move as opposed to a single contribution containing multiple

moves. The KBE developed to support this model required students to categorize their

contribution, the entire contribution, as a single epistemic move. This resulted in a

clarified constellation of epistemic moves. The KBE developed through the research of

the Knowledge Building community, Knowledge Forum (KF), did not require an agent to

categorize a contribution as a single knowledge type but instead allowed different

sections of a single contribution to be tagged as different epistemic moves. Therefore, a

contribution containing both questions and answers or more than one kind of answering

move was permitted and potentially encouraged. While both approaches have their pros

and cons, the approach advanced through PI provided stronger scaffolding, especially

helpful for students unfamiliar with Knowledge Building discourse. The visual models

created in response to research questions one and two are most easily situated in the

progressive inquiry approach.

2.3.2 Modeling knowledge-building as iterative knowledge improvement

The purpose of this section is to introduce the answer developed through this

literature-based philosophical inquiry to research question one, "How can the process of

knowledge improvement in science from a problem-solving perspective be succinctly

described?" The model developed, the knowledge improvement cycle (KIC) seeks to

provide a high-level, i.e., general understanding of the central activity of Knowledge Building: knowledge improvement. Similar to the progressive inquiry model, its aim is to provide a useful heuristic for students and teachers alike as they engage in their respective roles in a Knowledge Building classroom. The knowledge improvement cycle model becomes an element in the answers to research questions two and three.

Based on the historical overview of science presented in section 2.1, it can be seen that science has been commonly considered a problem-solving activity. Popper (1972) represented problem-solving as an iterative process with his "tetradic schema" Popper made several variations of the tetradic scheme to emphasize different aspects of problem-solving. The tetradic schema in Figure 2.1 illustrated a *tentative theory* proposed to satisfy the problem while the alternative tetradic schema he produced: Problem 1 $\rightarrow$ Tentative Solution $\rightarrow$ Problematizing activity $\rightarrow$ Problem 2 was used to emphasize a *tentative solution* as the solution to satisfy the problem. Because in both schema it is P_1, a "problem" that is being solved, it can be inferred that Popper considered "theory" KO's to be a specific type of the more general class of "solution" KO's. The visual model of progressive inquiry shown in Figure 2.4 also represents science as an iterative cycle. This idea of science as a process of iterative problem-solving will be further developed in this section.

Progressive inquiry's use of the interrogative model illustrates a relationship between a problem and a question. In the first stage of the progressive inquiry model students "Create the Context" for the inquiry by engaging with the phenomena. From a

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pedagogical perspective the purpose of this activity is not only for students to gain shared

experiential knowledge of the actual phenomena, but the purpose is also typically

designed to pique students' curiosity and hopefully induce the psychological experience

described by Dewey as that which initiates an inquiry: a cognitively uncomfortable

experience. This uncomfortable experience arises when some aspect of a phenomenon

"doesn't make sense" and is accompanied by the desire to remove that irritation. The

pedagogical aim of this stage is analogous to that of inducing cognitive conflict in

conceptual change models.

In this first stage, problems are experienced, explored and discussed resulting in a

problem description, possibly just discussed yet also existing possibly existing in physical

media such as written descriptions and questions of the discrepant event, perhaps

illustrations or a digital video of the phenomenon. In conclusion, the knowledge object

resulting from the "Creating the Context" stage is the elaboration of the problem space.

The next stage of the PI model aims at interrogating the research problem with

understanding seeking questions, typically why or how do… Questions seeking to

identify cause effect relationships though other types of explanatory relationships are also

valuable. The knowledge object resulting from this stage are the "big questions" that are

seeking understanding. These questions interrogate the problem situation with the

psychological aim of resolving the uncomfortable mental state, paralleled by the

epistemic aim of explaining the phenomenon.

In categorizing the elements in Popper's four-part problem-solving process, one notes that three of its elements: P_1, TS and P_2 are W3 objects while error elimination (EE) is a human-led activity. In other words, the result of this human activity of questioning or problematizing or the generic term for this activity, testing, is the new knowledge object, P_2. Perhaps because of Popper's interest in falsification, Error Elimination was the only activity included in his problem-solving schema. Missing from this cycle is the human epistemic activity that created the Tentative Solution, a KO such as a working theory. The human activity that creates this KO is sometimes referred to as "hypothesizing" or "theorizing" or "answering" but the more generic term "solving" will be used. As Knowledge Building is especially interested in creating and improving theories, i.e., explanations of phenomena, a reformulated problem-solving cycle is examined: Problem 1 → Solving activity → Tentative Solution → Problematizing activity → Problem 2. Research question one seeks a model to explain Knowledge Building, this five-part schema could be considered a solution. However, this schema only minimally cues understanding of the iterative aspect of problem-solving, in other words, has minimal utility as a heuristic for iterative problem-solving. Therefore, the nonlinear, visual representation shown in Figure 2.5 is the proposed solution to research question one.
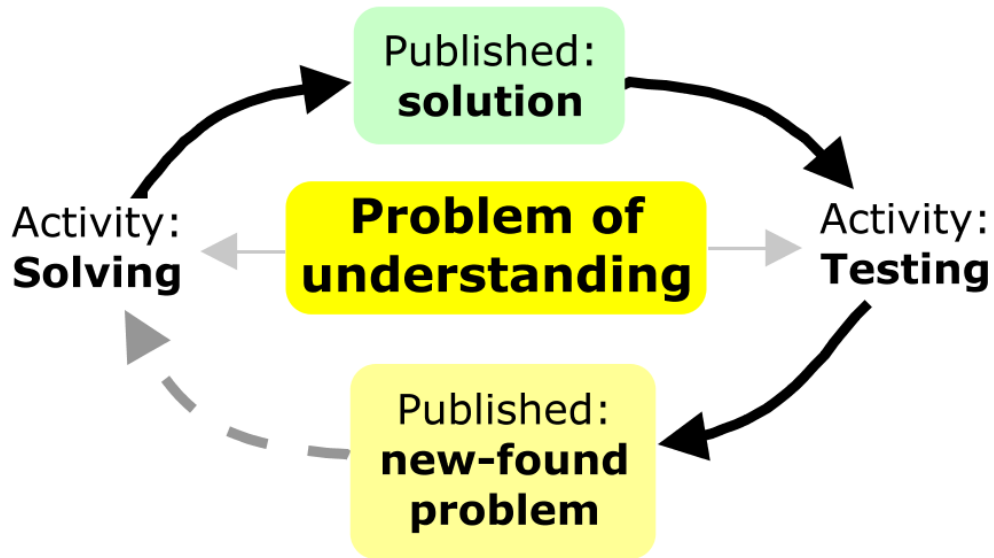
Figure 2.5: Five element knowledge improvement cycle (KIC).

At the center of this problem-solving cycle is, P_1, the problem to be solved. In opposing stances to the central problem are the complementary activities identified in Hintikka's interrogative model of inquiry. Of equal prominence and also in opposing positions around P_1 are the W3 products of the problem-solving activities: the Tentative Solution and the new problem, P_2. In summary, this schema places the problem to be solved in the center of the space while the problem-solving activities with their resultant knowledge objects cycle around the space. There is however a small but important difference in this schema from its previous, visually-linear representation. In the linear, only movement from Problem 1 to the Solving Activity is indicated, but in KIC the schema affords the understanding that progress is available from both Solving and Testing activities. That a problem-solving agent first interrogates the central problem with "big questions" is an essential aspect of Hintikka's model of inquiry and is illustrated in the PI model as described above. It is also quite likely that one develops a

solution to the problem without actively interrogating that problem first. This schema

indicates that both problem-solving activities are available. There are many types of

solving and testing activities. While the KIC represents a high-level view, i.e., an

overview of problem-solving, it can be used to provide more detailed information of the

cycle as shown in Figure 2.6 below.
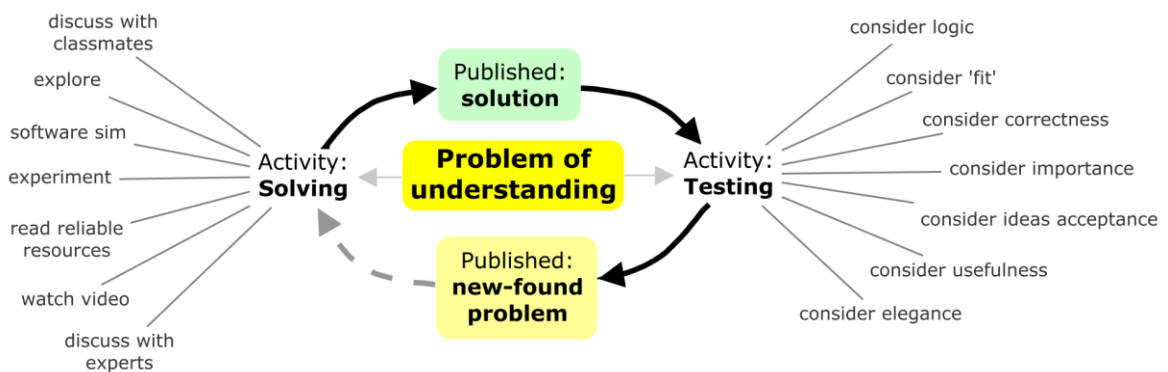
Figure 2.6: Example solving and testing activities in the high school science classroom.

As described earlier, problem solving can proceed directly from the central

problem to the "testing" activity however, testing activity is commonly performed on the

proposed solution. This testing activity seeks to discover important weaknesses,

limitations or inconsistencies of the "working theory" or whatever specific class of

solution is being tested. The final step of either type of activity is the publication of some

physical representations of the W3 object just created. This can include for example

annotated drawings or written description on a piece of paper, digitally in the publication

or the KBE such as KF or FLE. In whatever form expressed this material object is used to

communicate and perhaps illustrate the proposed solution or the new problem, P_2.

This KIC has several affordances for an agent building knowledge or seeking to lead a Knowledge Building classroom. It serves as a heuristic when seeking to understanding what happens in knowledge improvement. This question seeks to know types of activity involved in problem-solving and their possible relation relationships to each other it also clearly presents the products of these activities, and it shows they all revolve around a central problem one wants to solve. Indeed, once understood, this model can seem trivial as the pieces just seem to fit together. Furthermore, with its gray dashed arrow, the KIC visually represents the endless nature of the knowledge improvement cycle.

There are also limitations of the KIC model. First, the KIC fails to clearly represent that after engaging in problem solving the original problem state no longer exists: problem-solving is a transformative cycle expressed by the notation: $P1 \neq P2$. Popper's schema solved this problem using sequential subscripts for the Problems. However, neither the notation or the gray dashed arrow do more than confer future problem-solving iterations to one's imagination. Second, it is as common in a research field as it is in a KB class of students inquiring into the same problem space, that multiple agents may perform "testing" on the same published solution. This simultaneous testing is likely to discover several new problems in parallel resulting in several "problems" KO's are published at the same time. Likewise, competing solutions to the same problems can also be published in parallel. While the complexity of actual inquiry is beyond the affordances of the knowledge improvement cycle, the next section presents a

solution incorporating the KIC to address these two substantial problems of representing

of actual problem-solving discourse. The solution serves as the answer to research

question two.

2.3.3 Modeling actual KB discourse

This section presents the solution developed to answer research question number

two. While the knowledge improvement cycle represents the essential nature of

knowledge improving dialogue, it does not afford the representation of the progressive

nature of inquiry. When members of a community seek to resolve a big problem, perhaps

a dozen parallel branching iterations of this cycle will develop as the complex problem of

understanding is explored and solved and new and deeper problems apprehended. The

proposed representation, the KIC shown in Figure 2.5 is only sufficient to represent one

iteration. Additional or new representational logic was needed to visualize the

development of many extended and parallel/simultaneously-occurring discourse problem-

solving/problem-creating cycles. In the final solution the KIC provided the modular

element, that is the building blocks of an effective representation. However, various

representational systems were tested and rejected before creating this building-block

model of extended discourse. The following pages present a few of these representational

prototypes.

2.3.3.1 Branching Solving/Answering structure

According to the Interrogative Model of inquiry (Hakkarainen & Sintonen, 2002;

Hintikka, 1981), there is a back and forth interaction between nature and the inquirer.

Thus, a hierarchical or branching model was briefly considered. This representation afforded visualizing both the Question/Answer aspects of progressive inquiry and with its hierarchical structure, it implied breaking down an initial big question into smaller, answerable chunks. However, as it did not represent the iterative relationship that is argued to be an essential characteristic of knowledge improvement it was therefore abandoned.
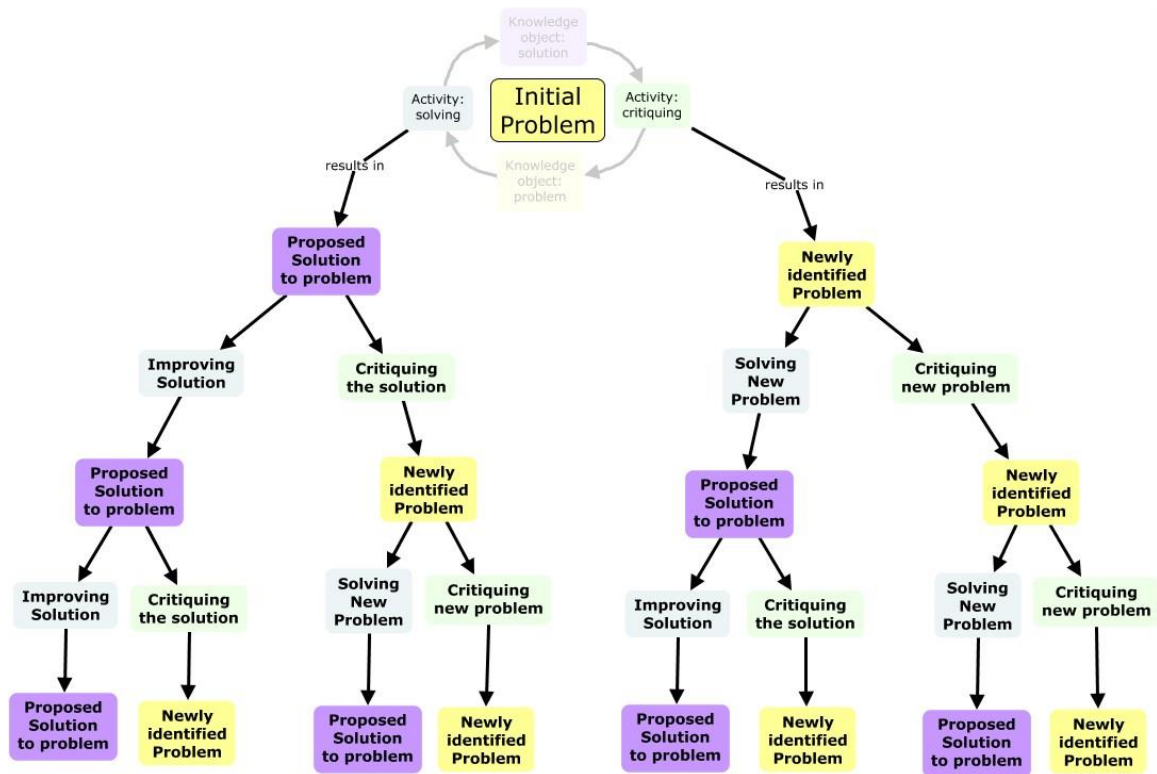
Figure 2.7 Hierarchical representation of extended KB discourse

2.3.3.2 Expanding cycles

A simple Google image search of "modeling cycle" or "design cycle" or "problem-solving cycle" shows the majority of representations of modeling cycles do not attempt to model the transformative aspect of these cycles. When attempted, there is

usually some visual hint indicating that the cycle repeats but with a different thread or possibly in third dimension such as a spiral. An example of this represented in two dimensions is the representation of the progressive inquiry model shown in Figure 2.4.

To remedy the PI visualization's lack of detail as well as difficulty in representing more than a single cycle of knowledge improvement, Toikkanen (2008) a lead developer of the Knowledge Building environment, FLE, created a detailed flow map of progressive inquiry Figure 2.8 . In addition to elaborating details of the progressive inquiry model (insert ref, this map nicely illustrates a few iterations of a KB cycle within that model. The diagram shows how the same process can repeat over time with variations Figure 2.4. However, it does not meet the need of being able to grow indefinitely as an actual discussion grows and would therefore not be useful in representing an actual discussion. Nor could it meet the design criteria of being able to flexibly represent unlimited and parallel (branching) iterations of actual KB dialogue. Additional representation based on concentric iterations of the KIC were explored as well as a figure-eight shaped design also with concentric components. Both of these models as well as a three-dimensional model with essentially the KIC cycles stacked one above the next were not successful.
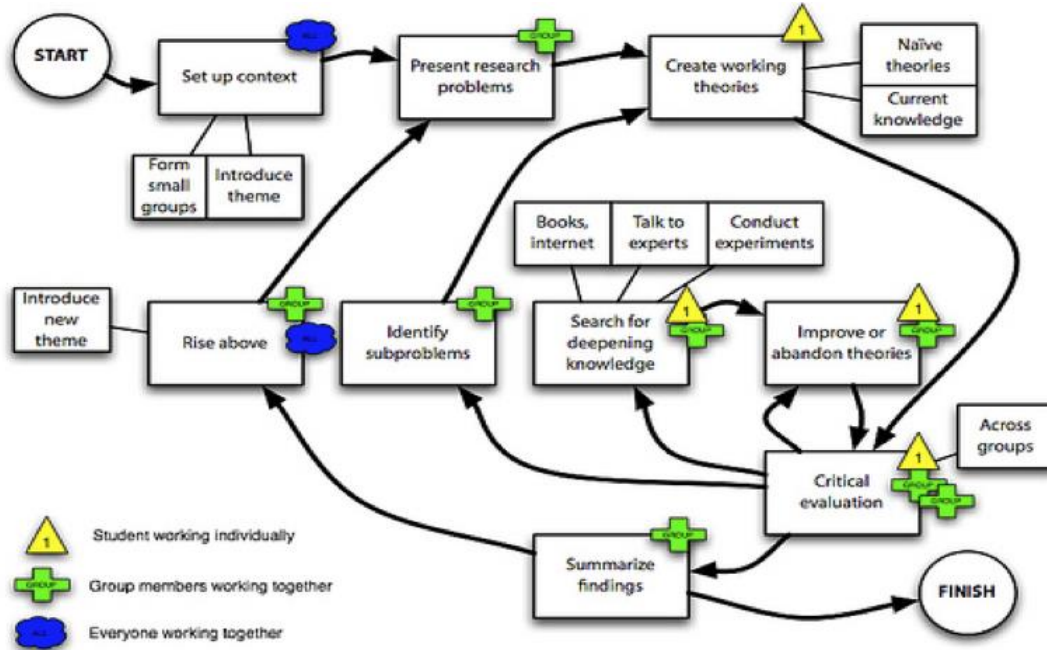
Figure 2.8 Toikkanen (2008) detailed representation of progressive inquiry

2.3.3.3 Knowledge Improvement Cycle as a modular design element

Finally, the idea of utilizing the KIC as a simple, repeatable design element, succeeded in meeting the design requirements for a Knowledge Building discourse map: that it is able to grow as does a KB discourse. In its most basic form Figure 2.9 it can be seen that instead of the published problem cycling back to the original problem, it instead spawns a new KIC, becoming the new central problem. This allows for unlimited KIC's while not losing the simple scaffolding of the KI cycle itself. In this sense, a KB discussion can be seen to be modular, i.e., composed of KI cycles.
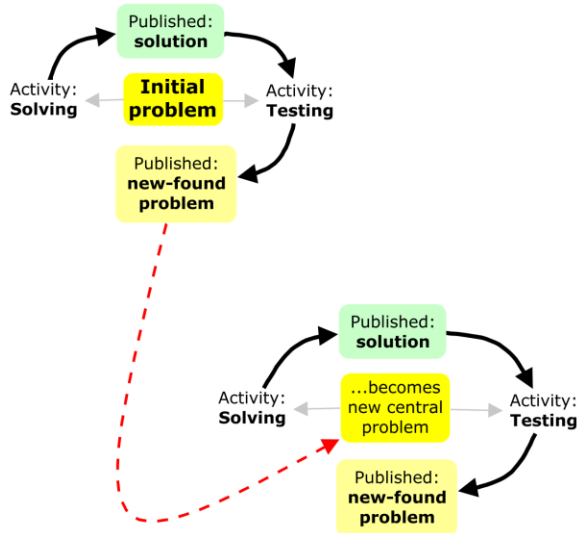
Figure 2.9 Representing Knowledge Building discourse.

To demonstrate how this representation also allows for flexibility in Knowledge Building discourse, a more complex discourse pattern is shown in Figure 2.10. In this representation, one solution is published to the initial problem. This solution is problematized in three different ways, each spawning its own KI cycle. This representation shows further flexibility, showing that it can represent those KB moves where the initial problem itself gets critiqued, spawning its own KI cycle. In conclusion, this representational system was satisfying in that it situates all KB discussion in a simple KI cycle yet it also represents the discursive relationships between these KIC's. In effect, this is able to show the actual branching of a group-wide conversation yet shows the unlimited iterations of the cycle as well as flexible growth and branching, i.e., parallel discussions.

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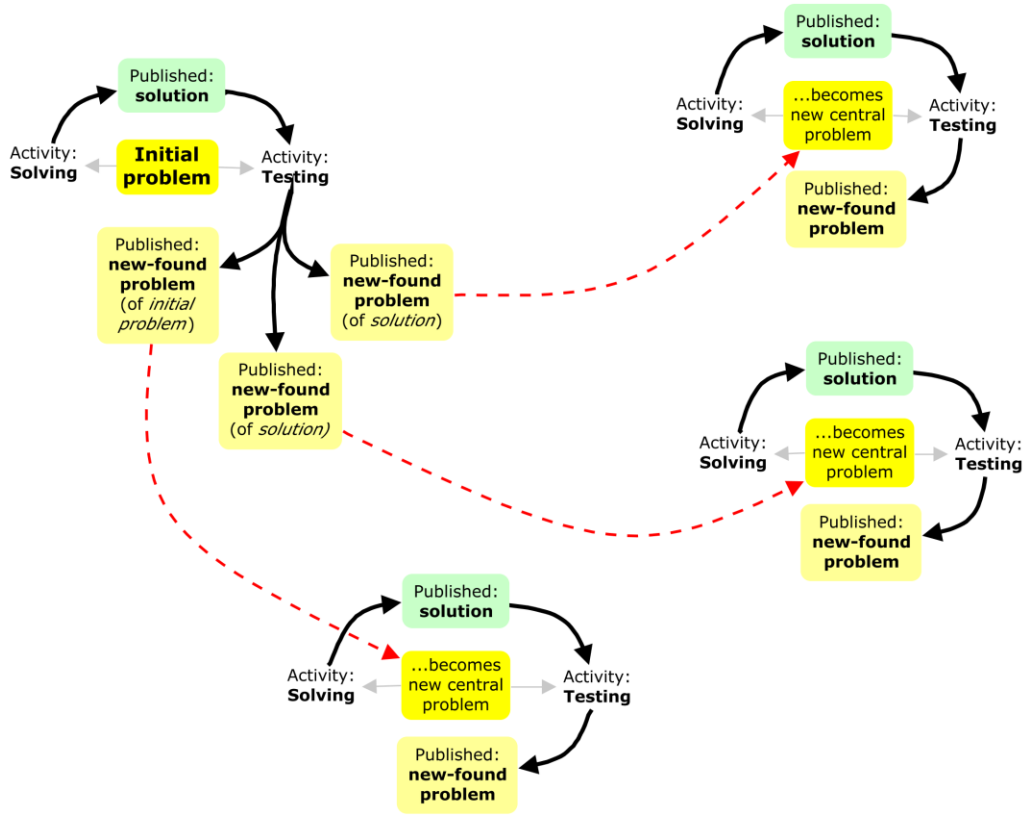
Figure 2.10 Example showing flexibility of representational approach

A further logic has been developed to represent sustained Knowledge Building dialogue. While it increases the complexity, it's branching structure allows for a higher density of iterations of knowledge improvement cycles. Shown in Figure 2.11 is a segment of dialogue in big question number one.

i believe that god did make us from his image, that monkeys may have some structures from us but we did not evolved from them,

E-T-S
E-T-P

I think you did a great job in explaining this theory, it is not proven, but perhaps one day we will see if it is true with our own eyes.

E-T-S
E-T-P

not everyone beilves in what scientist tell us.

E-T-S
E-T-P

well we did do an expirement with sporks and spoons & we found out that the adaptation changed with in time & so did the population

E-T-S
E-T-P

I think that humans evovled from afish like creature from the sea.

E-T-S
E-T-P

why do you belive that humans evolve from fish..

i agree with what your saying . i also think that we wont know unil we do our own research & see what we can find . cause like you said we only balive what the scientist say & we never know if they even did the reaserch

E-T-S
E-T-P

I think humans evolved from a fish like creature because we as humans only believe in what scientists tell us. We willnever know until we do the actual research ourselves. This seems to me to be a very creative or different way to explain the evolution of humans.

E-T-S
E-T-P

i agree with you

E-T-S
E-T-P

I believe that... We were created by God in His image.

E-T-S
E-T-P

what is the evidence that you have encoutered that makes you belive this

Well I go to the church and I read the blible, and the bible says that and I belive it.

E-T-S
E-T-P

Externalize the solution

Q1−From what did humans evolve? John

Externalize the problem

I don't think that they did, that's a common misunderstanding of evolution or so I hear. Try thinking of it more like humans and apes had a common ancestor, of course what you believe is up to you.

E-T-S
How could have apes had evolved into humans
E-T-P

Figure 2.11 Representational logic: solutions emerge from top, problem/questions emerge from bottom.

3   Instructional Context & Data Collection

From its initiation, the purpose of this study was to develop a useful and credible framework for understanding the Knowledge Building approach. In the unit of focus, students engaged in a six-week study of evolution. The instructional design and implementation were informed by KB and progressive inquiry (PI). Throughout this unit students engaged in a variety of activities described in section 3.3 including the activity central to this research, Knowledge Building dialogue mediated through Future Learning Environment 4 (FLE4), software specifically designed to scaffold this dialogue (see chapter 2). This software will be further described in section 3.3.2.2. Briefly, FLE4 was used intermittently throughout the six-week unit to provide a student-led space in which students could explore, make sense of, inquire into, and build knowledge around problems of evolution. Indeed, this Knowledge Building dialogue occurred around seven central questions created by students at the start of the unit in response to a highly engaging science video, "What Darwin Never Knew" (n.d.).

Chapter 3 aims to provide an understanding of the context from which the data used in this research emerged and the perspective from which it was interpreted and analyzed. It does this by first providing background information on the researcher who was also the classroom teacher and briefly the web servers, classroom computer network and computer-embedded tables developed for the pedagogical system used in this research. The epistemological perspective in which this research is situated is developed in detail in chapter 2 and is therefore not presented here. Next, additional context of the

classroom is provided including a description of the participants, the physical setting of

the classroom and the software infrastructure. In Knowledge Building and progressive

inquiry literature (at least in English) there is limited description of curriculum, teaching

or lessons involving the Knowledge Building approach. As this information is essential

for teachers and important for researchers, an overview of these things is provided here.

This chapter concludes with a description of how the data was extracted from the FLE4

server and imported into the FileMaker Pro database which supported the data analysis.

Note that the research methods are not included in this chapter. This is due to the unique

needs of research question three (RQ3). As developed in chapter 4, RQ3 was unusual in

that it required a hybrid philosophical -empirical method. In order to effectively present

this method it was felt that the research question, the unique demands of it, the methods

developed to interrogate it should be kept together, along with a mixed presentation of

the inquiry and analysis of the results. This was done to provide a greater understanding

of this uncommon method and concurrently make the process itself more transparent.

3.1 Researcher and classroom technology background

Especially for research where qualitative judgments are primary, there is an

intimate relationship between the researcher and the qualities of the knowledge produced.

Likewise, this same type of relationship exists between the teacher and the education

occurring in his or her classroom. For these reasons, background information of the

researcher and teacher, myself, is provided.

3.1.1 Personal background

My interest in becoming a teacher was not piqued until my second year serving in Peace Corps at 26 years old. Until that time my interests were paradoxically poised between science, engineering, crafts, and art; all I knew for sure was that I loved science and wanted to pursue it in some way. However, I was also committed to working to help people become empowered and somehow, science did not do this directly enough.

Upon leaving Peace Corps I entered Teachers College, earning a Master of Arts degree in secondary science education. Simultaneous to this I started to teach science in the New York City public schools, mostly at an alternative high school. Upon completion of my degree, I returned to and got a job teaching in a large Midwestern urban public-school system, teaching 10 years at an alternative middle school. Due to several years of district-wide downsizing that school closed as did the next two middle schools at which I taught. During this time, I earned my National Boards of Professional Teaching Standard (NBPTS) certification in early adolescent (11-15 years old) science education. In 2007, I moved to teaching science in high schools, mainly 9$^{\text{th}}$ grade. The study which provided the data for this research was collected in a 9$^{\text{th}}$ grade biology class in 2010-11. The next year was a leave of absence and was spent as graduate assistant as a student teacher supervisor and working on this dissertation. In 2012-13 I returned to teaching and renewed my NBPTS certification. The year after that I was awarded a sabbatical and again worked on this dissertation, and have been teaching at the high school (again mostly 9$^{\text{th}}$ grade) since then.

3.1.1.1 Identities as teacher AND researcher develop

It is not clear when my interest in also doing professional educational scientific research started. Since a young age science and invention have been my passion so it was natural for these interests to continue in my professional practice as a teacher. Through grants and especially the grant mentioned in the following section, I was able to instantiate a technology system which mediated patterns of communication that I considered essential in a science classroom such as a real-time chat organized around activities. In essence, the system was designed to scaffold the self-organization of each class community as a community of scientists. The system's design was complex and allowed much exploration and informal action research in its design. In 2004 my sense that I had a system of pedagogical inventions and understandings that was finally ready to begin to share and more formally develop led me to apply for a PhD in science education at the University of Minnesota. And it was in 2005, reading a brief description entitled, "Computer-supported intentional learning environments" (Dabbagh & Bannan-Ritland, 2005, pp. 177–178) that I excitedly saw that my complex vision of science education had a name: "Knowledge Building". From that moment, Knowledge Building became the gravitational center of my professional inquiry.

In conclusion, after 14 years of professional identities as a teacher and as a researcher coevolving, it is difficult to tease apart these identities and aspirations into two fields of practices. I know that any imagined vision of where I might be in 10 years is unlikely to share many details with where I actually end up, but at the center of this unfolding is the commitment to grow, to transform along with my communities and

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networks, through creative designing, critical reflections and action with friends,

colleagues and family.

3.1.2 Design of technological infrastructure

In 2001 with a grant from Medtronic Foundation I was able to improve on a

pedagogical idea using networked computer technology, initiated in 1998. Through this

project, mentioned in the preceding paragraph, a class set of six, four-person tables were

designed and built. Each table supported two networked iMacs swung under opposite

sides of the table viewed through glass ports. By the 2010-11 school year, the year the

data was collected for this research, the system had undergone repeated transformation

and elaboration including a class set of eight, second-generation computer embedded

tables using recycled computers running Ubuntu and other open source software. Using a

system called the Linux Terminal System Project (LTSP) the management and design of

this networked computer/software infrastructure was flexible to meet pedagogical

demands as the system maintenance was minimal. Vernier probe ware with LoggerPro

along with CmapTools and Firefox provided important functionalities to students and

teacher. Furthermore, three Internet Web servers, CmapServer, Plone CMS and the

WordPress Future Learning Environment server, providing essential pedagogical and

learning dimensions were developed and maintained. In conclusion this whole system,

from the physical, in-class components such as the tables and interconnected computers,

all the way up through the Internet Web servers, were considered a complex system. This

system's design was created and maintained, explored, adjusted and transformed by the

teacher/researcher over a decade, seeking to understand this complex system with the aim of growing communities of scientists.

3.2 Participants

The research was performed in an introductory biology class required of all incoming ninth graders. Specifically, the first period class was chosen for this study because, even though it was a smaller class than the others, there seemed to be greater openness in participation which it was felt would result in the broadest diversity of participation. This breadth of participation was important for the research goal of developing a normative model of science inquiry in the classroom. However, as it was first period, as is typical in high schools in this district, students struggled to get to class on time. As students had to walk to school from as far away as two miles, this problem was especially exacerbated during the winter months. While I had taught life sciences at the middle school level for years, this was only my 2nd year teaching high school biology. The class periods were 53 minutes long, five days a week, occurring throughout the entire school year. The data was composed of the set of student knowledge building contributions made in FLE4 during a six-week unit on evolution. Students had just finished a three-week unit on genetics, and before that had studied a three-week unit on cells.

This particular class had stabilized with 25 ninth grade students by the end of the first week of class, however as is common in this school, more students will leave than arrive over the year, thus explaining the 20 students present at the time of the study. Of

these 20 students present during the unit, three attended only infrequently. Of these three students, one attended more than the others and her posts are included in the data set. The second student never actually posted, and the third, while a member of our school for three weeks, was present only a few days and only produced one comment which was removed from the data set. Therefore, there were a total of only 18 students supplying the comments used as data for this research.

The participants include 11 girls and 7 boys, as identified by the teacher. The following demographics were also identified by the teacher: seven native Spanish-speakers, most born in Mexico or first-generation Americans; four native Somali-speaking students, also some born in Somalia or else were first generation; three White students; two African-American students and one native-speaking Hmong student. A majority of the students came from households where English was not the primary language spoken at home (as determined by family conferences and other forms of family contact over the year). Statistically speaking from data provided by school social workers, it is expected that several of these students were undocumented immigrants. The percent of students in the school formally labeled as receiving free and reduced lunches was 93%.

3.3 Curriculum and instruction

3.3.1 The unit of instruction

The content area for the target unit of instruction was Darwin's theory of evolution. Evolution was selected as the target instructional unit for several reasons. First,

the theory of evolution plays a central theoretical role in biology, organizing the entire discipline, indeed, "Nothing in biology makes sense except in the light of evolution" (Dobzhansky, 2013). Second, the timing of the unit was ideal. The school district's recommended sequencing places the teaching of evolution in the spring quarter. Third, this timing provided students with sufficient time to grow as a community including developing classroom norms and various competencies important to participate and learn in science. These academic and scientific competencies included: using software applications that were important in this unit, especially Firefox and CmapTools, including various Internet-based applications accessed through Firefox. These applications included PhET Interactive Simulations (n.d.), a collaborative version on our class intranet of Gowin's Vee Map, a heuristic used by students to support their empirical inquiry (G. Roehrig, Luft, & Edwards, 2001), and the central point for Knowledge Building discourse, the Future Learning Environment (FLE4) (Leinonen & Durall, 2014). The students had used the FLE4 software several times throughout the year, though never extensively and were still learning the interface as well as the concepts upon which the knowledge types were founded. Fourth, Darwin's theory of evolution is a complex topic and known to be resistant to conceptual change. Due to religious beliefs, Darwin's theory of evolution is controversial in the US culture as well as the cultures of the students in class who had immigrated from Latin America and Somalia. It was felt that these challenges would make Darwin's theory of evolution an ideal curricular focus for exploring the possibilities and challenges of Knowledge Building, as they would be more

likely to expose dimensions of pedagogical challenges that might not be revealed in less challenging topics (G. H. Roehrig, Groos, & Guzey, 2014). Finally, it was considered that the authentic peer to peer KB discourse inherent in the approach would be especially useful in addressing these challenges and helping students advance in their understanding of this foundational biological topic.

The instructional design involved a dynamic balance between, on the one hand a wide variety of activities generally considered constructivist with a variety of aims but most centrally, to help students understand evolution-related concepts, and on the other hand, the KB discourse on FLE4 which also had many aims including increasing knowledge-seeking and knowledge-building motivation, capacity to build knowledge with classmates, growth in fluency with using these ideas to build knowledge around the ideas of evolution as well as to learn evolution knowledge in a problem centered as opposed to referent centered manner (Bereiter, 1992). Figure 3.1 presents the timeline when students engaged in Knowledge Building through FLE4. Note that the first two events marked on the timeline are prior to the start of the evolution unit but are considered foundational: they help create the context for the unit.
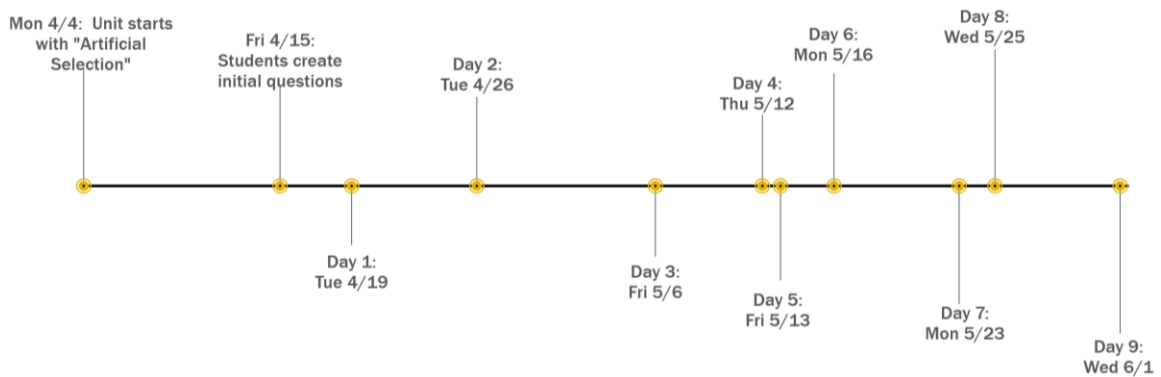
Figure 3.1 Timeline showing frequency of student posting to FLE4 during 39-day evolution unit

3.3.2 Instructional sequence

The following subsections provide an overview of some of the learning materials and activities in which students engaged over this unit. The progressive inquiry model provided a useful organizing heuristic to the unit and is used below to structure the following sections for the same reason.

3.3.2.1 Creating the context

Prior to the target unit on evolution students engaged in activities to come to understand ideas of artificial selection foundational concepts of evolution. On the first day of that pre-unit on the first day of Quarter 4, April 4th, students engaged in a pre-assessment on evolution, analogous to the post assessment they took at the very end of the unit. The assessment included two writing prompts, inviting students to theorize how a particular trait in a current day animal such as a cheetah could have come about, and three multiple-choice questions. Following the pre-assessment, students spent almost two weeks studying artificial selection and associated concepts, engaging with web simulations "Rare Breeds: Petunias" and "Biomorphs", culturally-referenced readings on

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the development of corn in the Americas and a project based on dog breeding. Important

ideas studied included: breeding also known as artificial selection, inheritance, traits,

variation, breeding population and phenotype change over time. The transition from

creating the context to setting up research questions occurred on April 15th at the

midpoint of the class period as described in the following paragraph.

3.3.2.2 Setting up research questions

On the first day of the evolution unit students watched the first 10 minutes of a

brief, high-interest introduction to Darwinian evolution, interrupted several times where

students recorded any questions that had come to mind. The video was, "What Darwin

Never Knew" (WDNK). Throughout the rest of the unit, short 5 to 15 minutes segments

of the WDNK video were shown, serving to bring advanced topics into our class

discourse. In the last half of class, in table groups, students transferred their questions to

Post-it notes and as a class organized them into related groups on the whiteboard, ending

up with seven groups of questions. I took a picture of these seven groups and over the

weekend chose one explanation seeking question from each group to represent that group

of questions. This resulted in seven, explanation-seeking, "Big questions" shown in Table

3.1. The body of contributions analyzed in this research were all of all of the comments

students contributed in their discourse around these seven big questions, Knowledge

Building questions.

Table 3.1 The Seven student-created big question for student KB discourse.	
Question #	**The big Questions:**
Q1	From what did humans evolve?
Q2	How did the animals in the Galapagos become different from the animals in the other parts the world?
Q3	What was it that made Darwin want interact with nature and species?
Q4	Why is the theory of evolution so important?
Q5	How exactly did Darwin's work get noticed?
Q6	How did Darwin compare the fossils to the species that were alive?
Q7	How did the animals who live on the island get there over time?

The Knowledge Building discussions occurred on our FLE4 website, essentially, seven webpages, one for each big question. **Error! Reference source not found.** is a screenshot of the second big question entitled, "Q2--How did the animals in the Galapagos become different from the animals in the other parts of the world?" Also note the associated questions shown below the big question from which the big question had been selected.

Q2–How did the animals in the Galapagos become different from the animals in the other parts of the world? Estela

Posted on April 18, 2011 by dgroos

- How did these animals adapt to these islands when their ancestors lived in totally different environments? Ashley
- How did one creature evolve into many? Alia
- Is evolution considered a theory or prediction? Tristen
- How can species go extinct when they reproduce every day? Estela
- What do they mean when they say, "1 animal produced all 4-legged animals" Sulieman
- How has the diversity of species changed over the years? Xochil
- What are the arguments for and against evolution? Tristen
- If evolution is true then why aren't monkeys still evolving? Tristen

Figure 3.2 Screen shot of top of FLE4 page showing Big Question #2 & associated question.

3.3.2.3 Constructing working theories

Two class days following the initial engagement with the idea of evolution described above, students reviewed the seven big questions, and as a table, chose questions they wanted to make sure got answered. As a team, students contributed answers to those big questions. It was not expected that these answers were "correct" but instead an opportunity for students to provide their personal "theories". These were seen as "working theories" to be explored, tested and improved or transformed. The following paragraphs illustrate how FLE4 scaffolded students' participation in this dialogue.

The Knowledge Building dialogue took the shape of a threaded discussion. As described in chapter 2, the software channeled students' participation through five general types of epistemic moves. The color of each post, that is "contribution", reflected the knowledge type selected by the student.

In Figure 3.3, three contributions are shown, the first two entries were posted on the first day of posting. They are of the "My Explanation" knowledge type, while the third is a "Problem-Question" knowledge type, posted roughly three weeks later. The next paragraph with two associated image provides a more detailed illustration of how the commenting system is scaffolded with the five knowledge types.

My Explanation

emej1402 *says:*

April 19, 2011 at 9:01 am (Edit)

I think that...the Galapagos animals mix and they created different species over the past generations.

Reply

My Explanation

athe1402 *says:*

April 19, 2011 at 9:07 am (Edit)

I think that the Galapagos is an unique place and so the creatures there, although perhaps coming from commonly known creatures around the world, have then been changed into something unique as well in order to adapt to this place. For another example the birds of Hawaii.

ideas from: Alia T

Reply

Problem-Question

tbai1401 *says:*

May 13, 2011 at 8:59 am (Edit)

Tristen why do they have to adapt to the galapagos islands?

Reply

Figure 3.3 Three student questions, the top two posts were made on the first posting day.

Figure 3.4 illustrates what a student would see upon first clicking the gray "Reply" link at the bottom of the yellow "Problem-Question" shown in Figure 3.3 and second, clicking on the "knowledge type" drop-down list. If the, "My Explanation" KT is chosen, one would see the pop-up window shown in Figure 3.5. Note the post to which the student is replying is shown at the top of the window. Furthermore, brief descriptive text corresponding to the selected KT is provided. The commenting window provides possible "sentence starters".

Figure 3.4 Commenting window illustrating the knowledge type drop-down box.

Problem-Question   tbai1401

#22   May 13, 2011 8:59 am

Tristen why do they have to adapt to the galapagos islands?

↳ Close

Leave a Reply

Knowledge type *

My Explanation ▾

My Explanation presents your own conceptions (hypothesis, theory, explanation, interpretation) about the problems presented by yourself or some of your fellow students. "My Explanation" is not necessarily well defined or articulated early in the inquiry process. However, it is crucial that the explication of your explanations evolves during the process and your working theories become more refined and developed. Are you presenting **your own thinking** (notion, hypothesis, theory, explanation or interpretation)?

Don't finalize your explanation. Post more elaborated versions later.

If you have knowledge from an information source, you should write a "Source-based Explanation".

Comment *

I think that...
I believe that...

Figure 3.5 The commenting window once "My Explanation" knowledge type had been selected.

Over the next almost three weeks students engaged with a variety of learning materials. The aim during this time was for students to both deepen their background knowledge of evolution and also to start to better articulate their own working theories as they responded to each other's posts. The students engaged with various learning materials and activities: a data generating, iterative activity called "Spork and Beans"

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(Burton & Dobson, 2009) illustrating important and abstract evolution concepts including populations, allele frequency, change in allele frequency over time and the concept, "survival of the fittest". Students expanded on the last activity by developing it as experiments using the online Gowin's Vee for scaffolding. Students watched a video and engaged with an online tutorial of Darwin's life and used PhET's interactive simulation of natural selection. During this time students understanding of the five KT's, especially "Scientific Explanations" was refined.

3.3.2.4 Critical Evaluation + Searching Deepening knowledge + Generating subordinate questions

Over the second half of the unit, FLE4 was used six more times, more frequently than in the first half of the unit as the instructional focus had shifted more towards building the community's knowledge. The class continued to watch short segments of the video WDNK as it was highly engaging and initiated discussion in class and activity on FLE4. Learning materials and activities aimed for students to engage with more advanced topics to evolution including, kinds of speciation, radioactive dating, misconceptions of evolution, cladograms, representing the iterative cycle of natural selection, investigations of examples of survival of the fittest such as antibiotic resistant bacteria and more. The last four days of this unit was split between students developing their own concept maps with a pre-defined list of vocabulary words, continuing to watch more of "WDNK", and on the penultimate day of the unit finished up the concept map and did final postings on FLE4. The next day students took the post assessment described in section 3.3.2.1.

The work during FLE4 included continued shaping of the meaning of the epistemic move implied in each knowledge type, a challenge recognized in FLE research (Arnseth & Säljö, 2007). Motivating students to go beyond what they already knew into conceptions they could not yet imagine was a constant challenge. I had provided a webpage on our Plone site with a 4 x 6 table, each cell containing an icon made from a reduced-size screen shot of a webpage that had served as a learning material during the unit. The icon was captioned and linked to the corresponding knowledge resource. This became a central launching point in students' inquiry, serving as a scaffold as well as being a mediating tool between the student and teacher and required knowledge. This scaffold supported the difficult step to search for the unknown needed to explain a difficult question or respond to a classmate's theory on FLE4.

3.4 Data Extraction and data analysis systems

The text students contributed to the seven big questions on FLE4 while engaging in Knowledge Building dialogue was the data for this research. The data informing this study included the contents of each post, its author, the time and date, the student-selected knowledge type for the comment and the commenting structure (to which comment a reply is made). All of this information was contained within the FLE4 WordPress database. While initial analysis was performed by simple inspection of the online discussion, the bulk of the analysis was done using two other systems and therefore required exporting the data from FLE4 in a form amenable to importing into other data handling systems. The next section briefly describes how the data was

extracted from the WordPress server. The following two sections describe how CmapTools and FileMaker Pro, programs with which I had close to two decades of experience, were used to perform the analysis of the discussion data.

3.4.1 Data Extraction

As the administrator of the WordPress site, I was able to download the data tables containing the data from the FLE4 discussions. I then hosted these data tables on a local MySQL server set up on my laptop using the open source MySQL server software for Macintosh. Using an open source client application for Macintosh computers, Sequel Pro, the tables were examined and those required were exported into CSV files. CSV files is a very common data structure and is easily used with Excel and also easily imported into the FileMaker Pro database in which the bulk of data analysis and coding was performed.

3.4.2 Non-linear data exploration with CmapTools

However, before using the FileMaker Pro database to analyze student comments, CmapTools was used to visualize the data in two dimensions. Student contributions were pasted into separate bubbles and the bubbles moved around in a two-dimension space. In essence, this was like writing each comment on a slip of paper and then sorting them into piles. However, CmapTools provided numerous affordances that streamlined the inquiry such as easy versioning, assigning colors and shapes the bubbles and connecting them with lines as needed. Furthermore, this tool supported collaborative data exploration with colleagues as we discussed patterns on the screen, moving the bubbles to illustrate and consider our ideas. Seven Cmap files corresponding to the seven big questions were

created and then populated with the corresponding student contributions, each in its own

bubble.

Printouts of these maps were also useful for analysis and were printed on 11 x 17

paper, the large-sized format required to be able to read the contents of the bubbles.

Furthermore, as the bubbles have been colored to match the color of the knowledge type

claimed by the student, the maps were printed in color to provide this information to the

viewer. Unfortunately, these maps are not included as the 11 x 17 format is a minimum

size for readability.

3.4.3 Coding in FileMaker Pro

Importing the data into FileMaker Pro from the CSV's was routine. The database

used approximately 10 data tables. Developing the initial data reports, i.e., views was

however challenging. Forty different views of the data were developed to facilitate

coding, sorting, annotating and filtering the data. A view might be adjusted several times

in a day as a new question for the data or new ideas for coding arose. In general, the most

useful views were those where the student contribution were represented with the color

representing the knowledge type and hierarchical indentations representing the thread

structure, similar to how it was presented online in FLE4. The screen shot shown in

Figure 3.6 illustrates one such layout (student name blacked out). While the process of

creating the exact view desired to explore a promising idea was sometimes challenging,

FileMaker Pro's flexibility and relative ease of use made this a tool that could be adapted

to almost any coding question I devised to interrogate the data. Chapter 4 presents the

research methods, analysis and discussion surrounding research question three. This work

is presented together due to the nature of this research question seeking knowledge that

was within, yet also beyond, what was present in the data.

Figure 3.6: Screen shot: view of student comments in FileMaker Pro database—Left side view

e Record   Find   Sort

Q |▼

Aa

Q1	Q2	Q3	Q4	Q5	Q6	Q7				

Sort thread   Shows Related Coding Local coding comment on this record
New coding comment_script_theory_approach   RandomComments

Advance Theory Design Explanation Solving My Explanation	144 144 144 144 Q1--From what did humans	--Q1-- "I" shows she isn't generalizing this. "We" is inclusive, saying we are all part of this group covered by "God", her god, which is an	Interesting--this didn't answer the question! The question implies that we evolved, but if you don't think so, it doesn't work, so it needed to be re-
Advance Theory Substantiate Explanation Testing Question	131 131 131 131 Q1--From what did humans	--Q1-- "the evidence" is explicitly identified as [those things] "that make you believe this". So, instead of using a deictic, explicitness is	___, seems to have figured out a new epistemological move, asking this 'why do you believe this' question...
Advance Theory Substantiate Explanation Solving Source-based Claim	127 127 127 127 Q1--From what did humans	--Q1-- "I" is used rhythmically, three times, showing ownership --and pride?-- in the statements shown. "the church" instead of 'my	Interesting meta comment--"it says so in the bible and I believe it".
Advance Theory Build Community around Explanation Solving My Affiliation	184 184 184 184 Q1--From what did humans	--Q1-- "i" connects the individual to the group of this thread. Also, "you" emphasizes the group--the audience is not telling the class with or maybe task completion?	
Advance Theory Design Explanation Testing Question	123 123 123 123 Q1--From what did humans	Q27-- ... is showing himself to be a questioner. He's not just asking 'any old question', he's asking how it could have come	When voting on the BQ's, one criteria would be, 'would the answer illuminate a 'hidden mechanism'? Also, the question specifies (proposes)
Advance Theory Substantiate Explanation Solving My Claim	125 125 125 125 Q1--From what did humans	Q27-- Complex-- Discourses include: building knowledge. role is explanation-provider from a more knowledgeable perspective. more No cite of source	Interesting, Here ___ is commenting/correcting someone's explanation from the very first day--april 19 on the very last day--june 1. She

Figure 3.7 Screen shot: view of student comments in FileMaker Pro database—Right side view

4 Methods, Theory Development & Results

"You don't understand the problem until you have developed a solution"

Jeff Conklin, 2008

Research question three was:

"What is a descriptive theory of Knowledge Building in the science class in terms of types of problems, epistemic and social aims that take into account the ideas of design and belief mode and the need to develop consensus around theories, along with the ideas of problem-solving and specific knowledge types?"

Chapter 4 aims to explain the answer to RQ3 and how it was developed. As philosophical inquiry methods are less familiar in science, aspects of the inquiry were presented. The inquiry occurred in two phases. Phase 1 of the inquiry was exploratory, searching for a set of promising and plausible theoretical components on which to focus. This exploration succeeded by eliminating many dead-end possibilities along with the identification of the main components of the final framework. These components included: major problem-types, cognitive modes of problem-engagement, the problem-solving process, KIC, developed in chapter 2 and the specific epistemic moves through which Knowledge Building is realized. Phase 2 of the inquiry was characterized by the iterative problem-solving process of positing of coding templates describing relationships within and between the aforementioned components, and then testing them on the classroom discourse data. Each iteration improved the fit between the promising theoretical components and the actual student contributions. This phase was considered completed upon successful interrater reliability testing. The next section develops RQ3 along with the sort of answer which would satisfy it. This is followed by the description

of the methods needed to provide the sort of answer sought: a hybrid philosophical-empirical method integrated into Template Analysis. Next, Phase 1, of the inquiry will be presented, then Phase 2, followed by the inter-rater reliability testing. Finally, limitations and significance will be discussed.

4.1 Answer sought by RQ3 requires hybrid methods

The Knowledge Building approach had been developing for almost 2 decades when I first started attempting it and different scaffolds for the teacher and students had been created. As a teacher seeking to grow and succeed in this approach, this support was needed. The software, FLE4, provided various scaffolds for students and myself to grow as a Knowledge Building community. Furthermore, there was the image depicting the progressive inquiry approach (Figure 2.4) that provided a high-level overview of the progressive inquiry pedagogical approach, founded in Knowledge Building. There was also extensive research literature base explaining Knowledge Building, however only a small part of it provided the type of information needed by the teacher. It is inferred that this detailed pedagogical knowledge was developed locally between researchers and teachers yet this knowledge saw limited publication outside of these local communities. Therefore, as I was not associated with any of these research communities, that is, as an "independent" Knowledge Building teacher I had available only the scaffolds provided by the software, the progressive inquiry diagram and the 12 Knowledge Building principles combined with my prior 15 years of experience implementing constructivist approaches. And in that sense, the Knowledge Building done by my students and myself

enacted only a limited view of Knowledge Building. It is important to understand this

context to interpret the following research question and methods.

4.1.1 A descriptive theory is needed

Initially, the third research question sought to create a model or some conceptual

object representing Knowledge Building. While the question, "What is Knowledge

Building" has been extensively answered, it was felt that the literature base does not yet

provide a description of Knowledge Building that, in the absence of researcher guidance,

is sufficient to scaffold a teacher to engage in the complex and ongoing pedagogical work

of developing high functioning Knowledge Building communities. Therefore, this

research was initially guided by the vague question stated above. As the inquiry

progressed to Phase 2, research question three clarified to become: "What is a problem-

solving perspective of Knowledge Building in the classroom?" This question does *not*

seek to identify causal knowledge of KB pedagogy. Instead, RQ3 sought to create a

broadly encompassing description for teachers' use, of what Knowledge Building *is*. In

other words, RQ3 sought a descriptive theory of KB useful for teachers. According to

(Fawcett & Downs, 1986): Descriptive theories are the most basic type of theory. They

describe or classify specific dimensions or characteristics of individuals, groups,

situations, or events by summarizing the commonalities found in discrete observations.

They state "what is." Descriptive theories are especially useful as they provide a

meaningful labeling structure of the system, allowing shared and systemic analysis.

As described in Chapters 2 and 3, there was an extensive theoretical foundation

for Knowledge Building. Yet, as argued in Chapter 1, a simple framework which united

some of these diverse theories was needed to help guide teachers, and potentially

researchers, in framing Knowledge Building in the classroom. Descriptive theory

provides a framework upon which other research can be performed, in fact, neither

correlational nor experimental research can be performed until descriptive theory has

been developed and validated (Fawcett & Downs, 1986). This is understandable as the

descriptive theory proposes a basic structure of the conceptual space being explored. It

posits that, if one considers Knowledge Building to consist of these specific components

related in these ways, one can design scaffolds to support, and decision frameworks to

guide, the emergence of Knowledge Building in a classroom community.

There are two categories of descriptive theory, naming and classification

(Stevens, 1984). The latter is more elaborate in that it is expected to show how

dimensions or characteristics of the phenomenon to be described are structurally

interrelated (Fawcett & Downs, 1986). Classification theories may be referred to as

taxonomies when hierarchy is implied. This research resulted in the development of a

classification descriptive theory. This taxonomy was the coding system developed

through this research.

4.1.2 When empiricism is not enough: a hybrid method

Descriptive research, also known as exploratory research, can employ empirical

or non-empirical methods such as philosophical research. In this study a hybrid of these

two approaches was employed. The descriptive theory sought through this research was a

description of what science *ought* to be in the science classroom, not what it *was*. As

described in section 4.1, the Knowledge Building episode that generated the data

analyzed in this research was not considered to be an idealized instantiation of Knowledge Building. Therefore, more than empirical methods were required: data can at most reveal a framework from which it emerged, not a framework from which it would have ideally emerged. In other words, the data alone is insufficient to answer the research question. According to Golding (2015, p. 206), "Philosophical research is in the realm of what should be—conceptually and morally—while empirical research is in the realm of what is". The third research question, "What *is* a problem-solving perspective of Knowledge Building in the classroom" is actually asking, "What *should* this perspective be?" and therefore, philosophical methods play an essential role in this study.

Theoretical philosophy	Philosophy with empirical	Philosophy applied to or informed by the empirical	Philosophical-empirical research e.g. Practical reasoning, Experimental philosophy, **Community of Inquiry**		Atheoretical data gathering
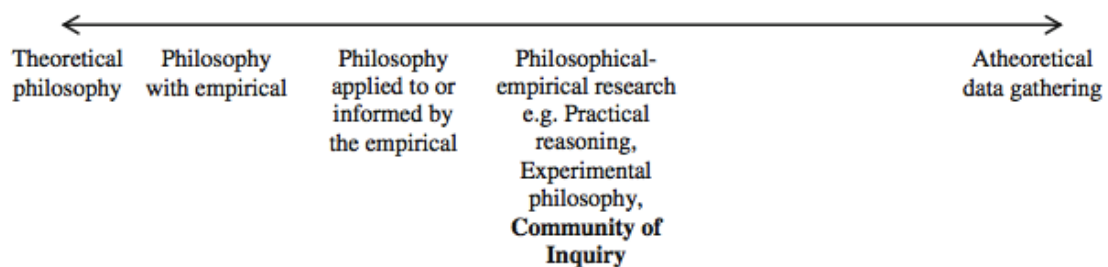
Figure 4.1 Continuum of research methods (Golding, 2015, p. 207).

As argued by Golding (2015) a hybrid of philosophical and empirical approaches may be called for in research that seeks to describe what both should be AND what is. As shown in Figure 1 above, Golding places theoretical philosophy at one end of a spectrum and atheoretical data gathering at the other end, listing a few hybrid approaches between these extremes. The process described by Golding as "the third option" in the following quote closely matches the process used in this current research.:

> *A third option in the middle of the continuum shown in Fig. 1 [Figure 4.1] is philosophical–empirical research that is at once philosophical and empirical.*

For example, we can go back and forth between philosophical arguments and empirical observations to form and test conclusions about the ''meaning and worth of possible pedagogical strategies, outcomes and contexts'' (Mejia 2008, 162). In other words, we find a reflective equilibrium between the philosophical and the empirical (Bufacchi 2004). We form philosophical conclusions about issues like classroom management, and then through empirical research we find a mismatch between our meanings and values and what we observe in the classroom, so we adjust our philosophical conclusions, and so on." p. 207.

With the incorporation of philosophical methods with the empirical methods, this hybrid approach gives priority to *both* existent data *and* diverse theoretical perspectives, permitting the development of a solution to the research problem.

4.1.2.1 *Template analysis structures philosophical and empirical inquiry*

In qualitative thematic analysis, the coding system developed is expected to be a representation of meaningful patterns in the actual instance with the aim to illuminate a research problem (Braun, Clarke, Hayfield, & Terry, 2018). And like in all empirical research, it is expected that the coding system not over reach the data that is, it should not describe something that did not exist in the event from which the data was collected. In this study however, while the former expectation, that the coding system credibly represent the data, is essential, the latter empirical tenant makes qualitative thematic analysis by itself insufficient when the research question includes a normative component. However, with appropriate integration of philosophical methods into thematic analysis, the answer developed to the third research question *was both* the coding system developed to describe and explain the students' KB discourse *and* a taxonomic descriptive theory. This is the case because the iterative, philosophical-

empirical process of developing the coding system for the data gave decisive significance to *both* the student data and the promising diverse theories.

Thematic analysis is considered to be more of a descriptive than an interpretive analytic approach though it is argued that descriptive analysis involves interpretation (Sandelowski & Barroso, 2003; Vaismoradi, Turunen, & Bondas, 2013). Thematic analysis is an adaptable approach applicable to a broad range of styles to organize and interpret qualitative data. King and Brooks (2017b) assert that:

> *Generic styles of thematic analysis are not wedded to any one methodological approach and underlying philosophy. Rather, they describe ways of carrying out analysis that you as a researcher need to tailor to the position your research is taking. (p. 5)*

Furthermore, according to King and Brooks (2017b),

> *All styles of thematic analysis include two interrelated core processes: defining themes that characterize significant features of the data, and organizing them in some kind of structure that represents conceptual relationships between themes. (p. 4)*

The features of adaptability, defining themes that characterize the data and organizing them in a structure to represent conceptual (as opposed to causal) relationships made thematic analysis a promising empirical candidate to integrate with philosophical methods.

4.1.2.2 *Template analysis: hypothesize coding themes, test on data, iterate*

Template analysis is one of these adaptable styles of thematic analysis describe above (Braun et al., 2018; King & Brooks, 2017b). Template analysis is generic in that no specific philosophical or theoretical commitments are required of the researcher. As

opposed to styles of thematic analysis such as grounded theory which uses a's strongly

inductive, "ground-up" approach to coding, template analysis tends towards the middle

using a somewhat more deductive, "top down" approach to coding. In contrast again to

highly inductive thematic analysis approaches such as grounded theory, template analysis

is more flexible in the sequence by which the coding structure is built up. In addition,

template analysis tends to support multiple hierarchical levels of coding, useful for a

descriptive theory.

While qualitative methods are typically described as inductive such as grounded

theory or more deductive such as template analysis, abduction as described in section

2.1.1 is invariably involved (Charmaz, 2008; Lipscomb, 2012; Reichertz, 2004; Suddaby,

2006). In the research presented in Phase 2 where hybrid methods were fundamentally

important, abduction served a correspondingly more important role as it "*Provides a*

more accurate description of the creative idea generation process involved in qualitative

methods" (Reichertz, 2009, p. 2). Template analysis commonly uses *a priori* themes, that

is, "*themes identified in advance of coding*" (King & Brooks, 2017a, p. 5). This coding

template is iteratively improved in essentially a two-stage cycle. First, an abductive

process creates or improves an *a priori* coding template that is based on theory and

empirical work. Second this coding template is tested on and improved through coding

the data. Yet, problems will be found in the template that cannot be solved with

adjustments to the template. Therefore, the basic structure of the template is transformed

based on theory and the empirical work creating a new a priori template and the process

repeats. This iterative process can be represented in simple form through the KIC (Figure 4.2). Template analysis' iterative process was adapted to incorporate hybrid methods as described in section 4.3.1.
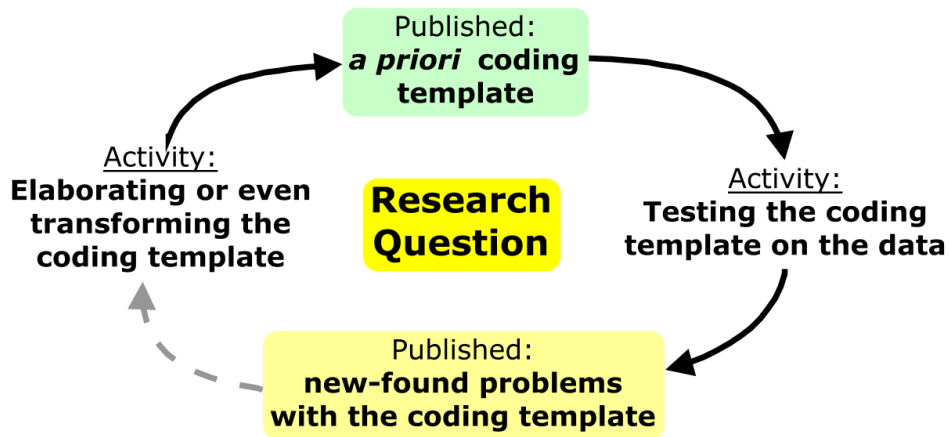
Figure 4.2 Template analysis represented as problem-solving in the knowledge improvement cycle.

King and Brooks (2017a) described a sequence of seven steps or stages typically, though not prescriptively, involved in template analysis. The first six steps are considered, "quality checks" while the last is the write up. Table 4.1presents these first six steps and their corresponding stage in the current inquiry. The first four steps were applied during Phase 1 of this research and are described in section 4.2. Section 4.3 describes how Phase 2 continued to incorporate the fifth step and the inquiry finished through step six. Step seven is the reporting. The following section describes how philosophical methods were included into the template analysis approach. This description introduces how this hybrid inquiry approach afforded the synthesis of coding templates from promising theories.

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Table 4.1 The six "quality check" steps of Template Analysis with phase of inquiry.	
Template Analysis: typical steps	**Engaged during**
1 - Familiarize with data	Phase 1 of Inquiry
2 - Preliminary coding	Phase 1 of Inquiry
3 - Clustering	Phase 1 of Inquiry
4 - Producing an initial template	Phase 1 of Inquiry
5 - Applying and developing the template	Phase 2 of Inquiry
6 - Final interpretation	Phase 2 of Inquiry

4.2 Phase 1 of Analysis: Data exploration identifies main components of template

The initial research question, "What is Knowledge Building?" presented no clear

path to its resolution and for that reason indicated the need for deeper exploration of the

problem space. Throughout this first phase of the inquiry, this initial vague question was

progressively refined. At the end of Phase 1, Research Question Three was fully

developed as was the initial coding template. The problem space can be described in

terms of two interacting types of information: theoretical and evidential. The first type of

information was the set of models and theories and concepts that I had identified as being

promising informants to the central question. The second type of information was the

body of data from FLE4 composed of all student KB contributions around their seven

central questions of evolution. These two types of knowledge objects were

simultaneously interpreted through my experiential knowledge of the students and the

lessons and curriculum and materials through which we engaged. Phase 1 of the inquiry

was structured through the first four steps or stages of template analysis, however with

promising theories serving a more significant role due to the hybrid philosophical empirical nature of this inquiry.

The first two steps of template analysis, 1) familiarization with data and 2) initial coding (King & Brooks, 2017a), were performed in order to provide the researcher with a deeper understanding of the data, that is, the student contributions. This deepening of understanding occurred through examining student contributions from different theoretical perspectives through different media. This exploration was supported by two technologies: the nonlinear data exploration was supported with CmapTools described in section 3.4.2 and the preliminary coding supported with FileMaker Pro introduced in section 3.4.3. Before presenting the exploratory coding however, the two initial conceptions of the promising theories that informed Phase 1 of this study will be described.

4.2.1 Theoretical foundations for Phase 1: two main sources

The first phase of this research was exploratory in nature, searching for a template that would scaffold Phase 2 of the inquiry by framing the deeper search for an understanding of Knowledge Building. This exploration was guided by two important ideas: a "good moves" model of Knowledge Building discourse and the "design mode versus belief mode" model. The exploration of student contributions was seen through the social linguistics view of language, specifically Gee's (2011a) argument that language builds our shared reality.

4.2.1.1 Bereiter emphasizes, "Good Moves"

Dialogue is central to Knowledge Building activity, indeed, Bereiter and Scardamalia (2016) assert that, "Collaborative knowledge creation is not only supported by, driven by, and reflected in dialogue but that it actually takes place in dialogue" (p. 12). Dialogue is a type of goal-oriented discourse (Walton, 1998), and like other goal-directed activity, can be conceived of as a series of strategic "moves" towards a goal (cf. epistemological move analysis (Öhman & Öhman, 2013). The interrogative model of inquiry, a founding component along with KB in the Progressive Inquiry approach, is explicit that the process of scientific inquiry process is a strategic, goal-tracking process (Mutanen, 2015). However, the goal need not, and usually cannot, be formulated before the process. This is due to the nature of knowledge problems: they are not "closed" that is there is not a single, correct solution or even a set of correct solutions, but are "open" where the goal or solution state emerges as the problem becomes better defined (Jonassen, 2000). Indeed, Conklin (2008) in his article that explores the solving of complex, "wicked" problems, states: "You don't understand the problem until you have developed a solution" (p. 14). Therefore, in Knowledge Building the epistemic goal requires periodic updating and defining. An important difference between a novice and expert practitioner is their capacity to make more effective moves and series of moves towards their goal, including progressive updating of the problem.

Conceptualizing Knowledge Building discourse as goal-directed activity invites one to consider the types of knowledge objects upon which work is done, for example problems, theories and mechanisms. One also can consider the aim of engagement of the

epistemic agent such as substantiating a claim, improving a method of knowing or understanding the relevance of the theory to their life. Considers the types of epistemic moves as one advances towards one's aims. It is important to note that the good moves model does not have to be limited to epistemic dialogue but is also relevant to social dialogue. For example, utterances are produced in order to gain acceptance with another or within a discourse community. Furthermore, dialogical moves can be aimed at building community around theories. All of these knowledge objects, dialogical aims and discourse moves are present as scientists discover and solve the knowledge problems of their field. The data exploration in phase 1 was intended to make explicit the knowledge objects, epistemic and social aims as well as the moves of students in my classroom as they engaged in Knowledge Building. The next section looks at the second foundational idea in the research presented in this chapter: the contrast between design mode and belief mode developed by Bereiter and Scardamalia.

4.2.1.2 Scardamalia & Bereiter's Design mode vs Belief mode model

Of central interest to this research is Bereiter's and Scardamalia's (Bereiter & Scardamalia, 2003; Scardamalia & Bereiter, 2006b) model of design mode versus belief mode as introduced in Chapter 2. Design is a ubiquitous activity that is practiced in everyday life as well as in the workplace by professionals (Schön, 1983). It is not restricted to any specific discipline such as art or architecture, but instead is a broad human activity that pursues the question of "how things ought to be", as compared to the natural sciences, which study "how things are" (Simon, 1996). It is a fundamental activity

within all professions: architects and urban planners design buildings and towns, lawyers design briefs and cases, politicians design policies and programs, educators design curricula and courses, writers design novels and technical documentation, psychologists design experiments, and software engineers design computer programs. Designers solve problems. Design mode describes the mode of working that drives innovation, the product of primary value in the knowledge age. "In design mode we are concerned with the usefulness, adequacy, improvability and developmental potential of ideas" (Bereiter & Scardamalia, 2003, p. 3). In Perkins terms, in design mode we are concerned with the structure of knowledge and what that structure can be used for and how it works. As described in section 2.2.1, in 2003 Bereiter and Scardamalia first advanced a contrast between Design and Belief modes. This contrast was used to distinguish what was unique about the Knowledge Building educational approach (Bereiter & Scardamalia, 2003, 2016; Scardamalia & Bereiter, 2006a, 2007). In design mode we consider how an idea works and consider new structures, designs, that might work better. When we consider an idea in belief mode we wonder if the idea is true, if it is correct. It is the mode we emphasize when we are concerned if some idea is worth believing.

Bereiter argues that school emphasizes "belief mode", not design mode and is thus not well aligned with the main competencies required for participation in the knowledge age. Previously, the warrant for the validity of knowledge in schools was provided by authorities such as the teacher and the book. With the recognition of the importance of students understanding of the nature of science such as how we make

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reliable knowledge in science, the focus turned from a dependence on authority to a demand for reliable evidence that supports a claim and reasoning that both makes clear how the data counts as evidence for the claim and also how this claim is consistent with accepted scientific theory. This recognition of the significance of the nature of science and especially empirically-based methods is demonstrated by the focus on inquiry in the National Science Education Standards (National Research Council, 2000). This empirical method was reified in the "Essential features of classroom inquiry and their variations (National Research Council, 2000) (Bybee, 2011). This belief-mode approach is explicitly represented in several of the practices of science in the NGSS such as, "*Engaging in an argument from evidence*" (NGSS Lead States, 2013). The concern for the validity in school disciplines is essential. The dominance of belief mode in education seems common sense: students should be expected to learn (true) facts and laws, as well as theories that are confidently known to be reliable and how to develop and ascertain reliability. Indeed, this concern for validity is what distinguishes knowledge from belief and conjecture. However, there are problems with a dominance of belief mode in schools even, or especially, in science education. Bereiter and Scardamalia have recently changed the name of belief mode to critical mode (Bereiter & Scardamalia, 2016) though in this research the term belief mode will continue to be used as "critical mode" itself has multiple meanings.

The value of design mode in school includes challenging students' epistemic relationship to knowledge. Placing a central emphasis on students learning true

knowledge along with how it is substantiated, a particular epistemic relationship between the student and the knowledge objects of science. Knowledge objects are seen as static, perhaps even in a "perfect" state, affording a passive or unquestioning relationship between the student and scientific knowledge. However, students engaging in education based upon design mode yet balanced by belief mode develop a creative and critical epistemic relationship towards these important knowledge objects, the products of our scientific culture. In design mode, students co-create and over extended time improve and transform knowledge objects. Specifically, in a Knowledge Building science class, students ideally discover important problems of understanding, and as a member of a Knowledge Building classroom community solve these knowledge problems over an extended time. Over time students understand how theory is developed including when the need arises, how it is substantiated. Students' relationship to theories becomes sophisticated and they are for example, more resistant to persuasive presentation of sophisticated theories that are supported by verifiable facts that counter global warming. Students gain a certain kind of confidence as a co-creator of knowledge. And as members of the community that discovered the problem, interrogated it, researched knowledge sources they assessed as authoritative, applied this knowledge to solve the original knowledge problem, and furthermore transformed problem, they consider themselves co-creator's of knowledge, active members of the knowledge age.

4.2.1.3 *How language builds the world: social linguistics*

Briefly, the social linguistics view of language grew in importance during this phase. It is founded on the belief that what is said, in whatever medium, attempts to build a world in the social sphere, according to the interests of the 'speaker' (Gee, 2011b). A communication cannot be fully understood by referring to word meanings in a dictionary—the word meanings are situated in the particular context. This understanding of language illustrates that simply looking at the words written by a student in their contribution will not necessarily indicate their exact meaning nor the "world building" constantly being performed. Critical discourse analysis was explored to interpreting the meanings a speaker gives to their utterances and was used towards the end of the first phase of inquiry and occasionally throughout the second phase to help determine the cognitive mode of a contribution.

4.2.2 Familiarization with data from theoretical perspective

The theoretical foundations presented in section 4.2.1 provided the theoretical sensitivity which suggested a sparse template to accomplish the goals of the first two stages of template analysis: 1) familiarization with data and 2) initial coding (King & Brooks, 2017a). Throughout most of Phase 1 of the inquiry, the focus was on understanding the different types of epistemic moves made by students. It was abduced that this knowledge would support identifying effective patterns of epistemic moves, i.e., "good moves" an important part of the vague research goal of understanding Knowledge Building. It wasn't until the end of Phase 1 that the design mode versus belief mode contrast took on great significance.

The first two exploratory coding efforts included only the student contributions made in response to the first central question: "From what did humans evolve?" (referred to as: Big Q1). In both of these two coding efforts, all 47 contributions in Big Q1 were coded, starting with the first and proceeded in order through the following 47 contributions. The coding order of contributions used was the same as that in which the contributions were ordered in the threaded view on the FLE4 page: chronologically at the top level of threads, and by response structure within the thread.

In both coding efforts, the root level of the coding system (Level 1) was pre-populated with three *a priori* categories. Two of the categories were typical epistemic knowledge objects: "questions" and "answers", used in making the two basic epistemic moves according to the interrogative model of inquiry (Hakkarainen & Sintonen, 2002; Hintikka, 1981). The third category in the template was conceptualized as "social" for contributions that neither ostensibly seek nor provide science related content such as "I agree" or "I disagree". This is not to say these types of contributions serve no epistemic role. As described in section 4.2.1.3, every speech act is a world-building move and provide important and complex functions in a knowledge creating classrooms (Brown, Collins, & Duguid, 1989; Gee, 2011a; Hakkarainen, 1998).

4.2.2.1 Coding exploration one

Table 4.2 shows one segment of the results from the first coding effort, the codes that were "children" codes of the most general, "question" coding category. It was felt that it is important to show an important segment of the code-structure to give a sense of

the initial inquiry into the data, omitting the rest of the codes as this was only an exploratory stage. The section of the coding structure following from the "Question" Level 1 category was chosen to be shared as the role of questioning and therefore the knowledge type, Question serve a central role in inquiry. In the first coding effort contributions were initially categorized (Level 1) by the general type of move they made, as described above. For example, the contribution "*Why do you think that*?" was categorized as a question. In the "question" move there were two, "Level 2" categories that developed based on "General Sentiment" including: "Not understanding" and, "Disagreeing". Both of these general sentiment categories further fork in the "Specific sentiment" Level 3 as seen in Table 4.2. The "epistemic aim" as well as an action plausibly being sought by each aim were entered in Columns 4 and 5 respectively. These columns contain inferences from the Level 3 code, elaborating that code and therefore are not considered levels of code and instead are given Column numbers. During the coding process, sister-categories deduced from theory and not identified from the data were also entered in to the coding system as the goal at this stage was to consider epistemic moves and the specific knowledge work they do. There was one example of theory-deduced codes in Table 4.2, indicated by the lack of a corresponding illustrative quote from the data in Column 6. The specific sentiment that were deduced from theory was "That idea doesn't work", deduced from the design mode idea that knowledge ought to be tested to see if it "works".

Table 4.2 "Question" section of coding system resulting from first coding effort

Level 1 Epistemic move	Level 2 Reason made	Level 3 Specific reason	Column 4 Epistemic aim	Column 5 Response sought	Column 6 Example contribution
Question	Not under-standing	What are you saying?	Understand contribution	Edit or clarify contribution	*"What do you mean?"*
		How could this happen?	Seeking a model or explanation	Propose a model/ explanation	*"How could have apes had evolved into humans?"*
	Dis-agreement	Doubting the truth of a claim	Seeking truth or correctness	Provide authoritative knowledge/ argument	*"What's the evidence that you have encountered that it makes you believe this?"*
		That idea doesn't work	Seeking to know how well an idea solves a problem	Provide analysis of effectiveness of idea	
		That doesn't seem right	Seeking (internal) idea consistency	Propose solution to a problem found in an explanation	*"But then why do both monkeys and humans still live?"*

As is expected in the initial stages of template analysis, this coding system was discarded however important learnings were carried forward to the next coding effort. To interpret the sentiments and epistemic aims of a comment, it was often important to know its context, in other words to what it was responding. For example, the question shown in the top role in column six from table 1, "*What do you mean?*" was in response to this contribution, "*I believe that humans evolved from an ancient monley (sic) that then later as time passed was created into a human from bone*". The contribution, "*What do you mean?*" could express disagreement however, considering the statement to which the question was directed indicated it was trying to clear up a confusion. Furthermore, I noted

that my knowledge of the students, their identities constructed over the year and the relationship between students who were responding, was sometimes significant in making the inferences required by the coding. For example, the response to the question "*What do you mean*?" was the unhelpful, "*He just said what she means*." Knowing the developed identity of the student who posted that response, it is likely that he was trying to irritate the original poster who was a girl, and possibly the rest the class although there are other possible goals of the utterance. Because of this inference I coded it in the Level 1 category, "social" as "disruption" instead of as "showing support for another student". With the aim of understanding the Knowledge Building dialogue from an epistemic moves perspective it was considered that the FLE4 data that had been collected would most richly provide information on the epistemic aim intended by an agent with their contribution. Tentatively, ideas related to the design and belief mode contrast were also considered such as "seeking to understand" versus "seeking any argument". A new coding effort commenced.

4.2.2.2 Coding exploration two

The second coding effort explicitly focused on exploring the range of epistemic and social aims of the student contributions (from Column 4 in Table 4.2). The Level 1 categories of the coding template was again pre-populated with the same categories as the first coding effort: the two basic epistemic moves from the interrogative model, Questions and Answers, and the category for contributions that were considered not specifically epistemic, Social. Similar to the first coding effort, coding was performed on

the 47 student contributions in Big Q1 in the threaded order they were presented on the

discussion screen. Also, like the first coding effort, the hierarchy and categories after

Level 1 were inferred from the student contributions. In short, contributions were coded

by the type of information they sought or provided, especially based on if their aim

seemed to be in design or belief mode. The contributions coded as social were mostly

expressions of agreement or disagreement. Table 4.3 presents only the Question segment

of the second coding structure. Fourteen of the contributions in Big Q1 were questions.

The table is discussed below.

Table 4.3 "Question" section of coding system resulting from second effort.

Level 1 **Aim**	Level 2 **Specificity**	Level 3 **Type of info**	Level 4 **Detail type**	Column 5 **Example contribution**
Question	Seeking ANY information	Seeking any argument		*"Why do you believe that humans evolved from fish?"*
		Seeking any related idea		
		Seeking to understand writing		*"What do you mean?"*
	Seeking specific information	Seeking an explanation/model		*"How did humans evolve from fish"*
		Seeking utility of explanation		
		Seeking validity of explanation	Seeking source of info	*"I don't remember this, perhaps I missed that lesson."*
			Seeking a supporting fact/ evidence	*"What is the evidence that you have encountered that makes you believe this?"*
		Seeking to understand post	Seeking details	
			Seeking definitions	
			Seeking meaning of sentence	*"Humans evolved from fish 'and' humans? Excuse me, but I am rather confused by this?"*
		Seeking social context		*"Who influenced you to believe this?"*

Level 2 in this coding system categorized the level of specificity of information being sought as it was felt that more specific searches, whether for a fact or theory or an argument, would lead to more effective epistemic advancement. Level 3 categories identified the type of information sought or provided, especially privileging Bereiter's design/belief mode contrast, that is, based on whether the contribution was seeking to

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understand and idea or attending to the belief worthiness of it (see section 4.2.3.1). Level

4 provided space for more detailed categories when the contributions seemed to need

more detail than available by the Level 3 code. For example, both of the contributions, "*I*

don't remember this, perhaps I missed that lesson.?" and, "*What is the evidence that you*

have encountered that makes you believe this?" shared the same Level 3 code:

Question→Seeking-specific-information→Seeking-validity-of-explanation, yet were

seeking significantly different kinds of information. Therefore, this particular code was

bifurcated into, "Seeking source of info" for the former quote and "Seeking a supporting

fact/evidence" for the latter contribution. Similar to the first exploratory coding effort, as

seen by the cells in Table 4.3 with missing contributions in Column 5, there were four

sister categories that were deduced by theory and were not represented in the

contributions. These were added to the coding structure as contrasts to codes that were

included, again supporting the consideration of a broader range of aims than were evident

in the small part of the data that was coded.

Several important things were learned from this coding effort. The concept of the

two important types of knowledge objects provided by the interrogative model of inquiry,

questions and answers, allowed the contributions to be confidently distinguished. And the

interrogative model itself continued to appear promising. Likewise, the concept of

epistemic moves with accompanying dialogical epistemic aims provided by Bereiter also

continued to show itself as fruitful, producing a diverse set of epistemic moves, also

fairly easily distinguished with the context available to me. However, a difficulty in

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advancing towards identifying patterns of, "good moves" in order to help understand KB was seen.

There were two factors that when combined led to a significant change in the research goals. First, in coding only Big Q1, there were 27 types of information being sought and provided including in the Social category. While it was true that a number of the codes were developed from theory and were not seen in the 47 student contributions coded up to that point, it was felt that the categories were far from being saturating by the moves in which my students engaged, and that there would have been significantly more when all 200+ comments were coded. Second, as can be seen in Figure 4.3, there was a limited supply of long threads to serve as epistemic units where the progression of knowledge transformation could be assessed. Perhaps due to students and teachers limited experience with FLE4 combined with insufficient affordances of the tool to encourage extended threaded conversation, there were many instances of epistemic progress seen across threads and even across big questions. Taking these two factors into account, the limited quantity of extensive threads showing significant knowledge advancements with a large number of specific epistemic moves, it was concluded that the "good" aspect of "Good Moves" was not achievable. This is because, to identify patterns of knowledge advancement, many contributions that were intentionally build off of each other in a conversation, ideally identified by coding categories that were saturated, would be needed. Changing the focus of the research from identifying types of discourse patterns associated with effective Knowledge Building to instead figuring out the more

fundamental question, what is Knowledge Building in terms of epistemic moves and

corresponding knowledge types was seen as both more achievable and that it sought

knowledge that was more basic, that is a descriptive theory, explained in . There was one

more concept of Knowledge Building tested in the second coding which further informed

the direction of this research, that is Scardamalia and Bereiter's contrast of design mode

and belief mode. The conclusions and that their important impact on the research are

presented in the following paragraph.
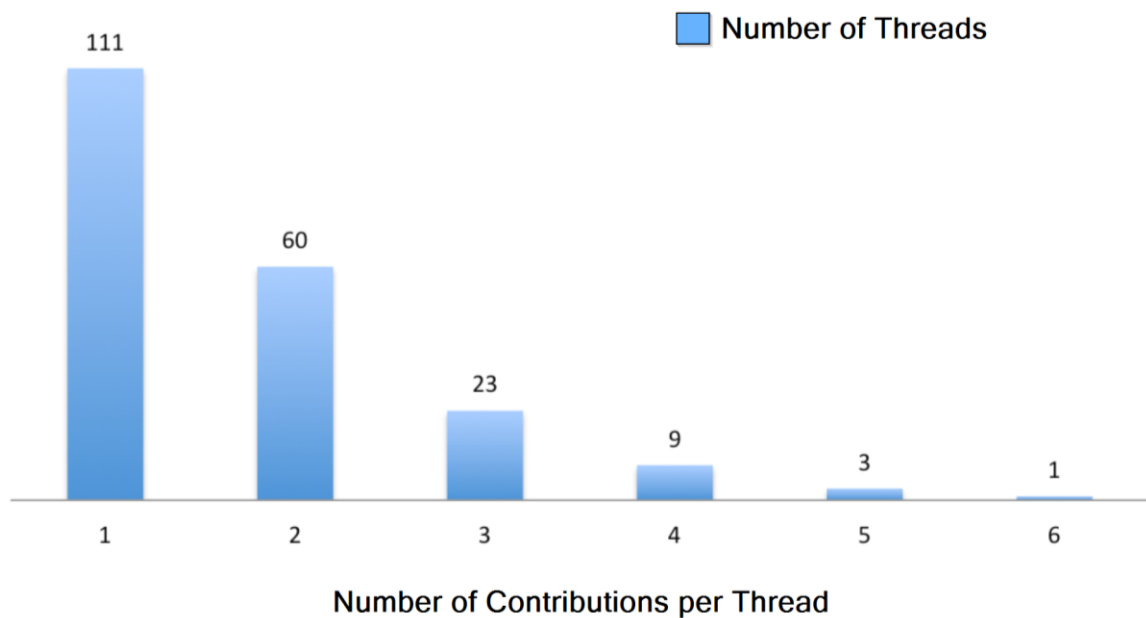
Figure 4.3. Count of threads organized by number of contributions in the thread.

Substantial challenges in identifying the mode of a student's discourse move were

encountered. Some contributions such as #31 in Big Q1 were fairly easily identified as to

their mode: "*What Kind Of Evidence Do Scientists Have About Humans Coming From*

Animals? I Think That We Are Created By God (Allah) And His Power. So Obviously I

Don't Think We're Made From Animals." This student was asserting a lack of interest in considering the concept of evolution as an improvable knowledge object and instead her concern was of the truth or more specifically the lack of truth of the theory of evolution and therefore this contribution was coded to be in belief mode. Other comments however such as, "*Why do you think that?*" are more ambiguous. It was not clear if the author was searching to understand the other persons ideas of how the theory of evolution works or its effectiveness at explaining certain phenomenon and therefore considered to be a design mode question, or if the author was trying to figure out if the concept of evolution was true and therefore considered to be a belief mode question. Furthermore, contributions such as, "*Who influence you to believe this?*" and "*That is an interesting viewpoint, I am not religious, but I think it was a good idea of yours to say this.*" appeared to have more social aims and it was not clear how that might integrate with the design/belief mode contrast. Notwithstanding these challenges, there was no indication that this design mode versus belief mode model was less promising.

Two components of a solution were identified to resolve the problems of distinguishing the mode in which contributions were made. First, discourse analysis methods were expected to be needed to distinguish the mode for some contributions and furthermore to sometimes be needed to determine towards which purpose or purposes a social comment, builds. Second, it was concluded that the model of design mode and belief mode provided in the literature needed to be elaborated and made more fine-grained in order to identify these modes in the students' epistemic moves and furthermore

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understand the roles of these modes in social moves in the context of the students' KB contributions.

The development of the design mode versus belief mode model was the last problem to be solved in order to pass through stage three of template analysis: the clustering of the main themes and categories that had been identified. The process of organizing the themes in stage three was accomplished simultaneously to stage four of template analysis: the creation of the initial coding template. However, in the process of elaborating this design/belief mode model, I explicitly re-bracketed my theoretical framework to equate "design cycle" to "iterative problem solving." Through the process of re-bracketing, the knowledge improvement cycle (KIC) and "Problem Types" were situated as significant components of the coding template, too. Taken together, the literature-based work done in developing the concepts of design and belief mode required constant testing of these ideas on the data, resulting in the further elaboration of the problem space of this research. At the end of the work described above, the final version of the research question which was identified as RQ3 emerged: "*What is a descriptive theory of Knowledge Building in the science class in terms of: types of problems, epistemic and social moves that take into account the ideas of design and belief mode and the need to develop consensus around developing theories, and problem-solving using specific types of knowledge objects*?" Stage 5 of the analysis involved applying the initial template composed of the elements mentioned in RQ3 to the data. And through the iterative hybrid process described in section 4.1.2, the template was iteratively improved

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and transformed. This work was performed in Phase 2 of this research and is reported in section 4.3. The development of the design mode/belief mode contrast is however first presented in the next section.

4.2.3 Coding demands development of design/belief mode concepts

In this section, the concept introduced and described by Scardamalia and Bereiter in several papers, design mode versus belief mode, is developed through diverse literature and further exploratory coding. As discussed at the end of section 4.2.2.1, inferring whether a contribution was made in design mode or belief mode was considered to be important in understanding Knowledge Building, yet only sometimes was categorize the mode of an utterance conclusive. According to Bereiter, design mode discourse was manifested when the aim of the discourse was understanding or improving the structure of the design. While belief mode, i.e., critical thinking mode, was manifested when the epistemic aim included addressing ideas of correctness or truth. Because the contrast was identified to be of such significance in the success of Knowledge Building communities, and because seemingly closely related ideas are broadly considered significant in creative practices, distinguishing between design and belief mode grew in importance as the coding and design/belief mode model elaboration progressed.

4.2.3.1 Design and belief modes: Related conceptions from diverse fields

Several researchers and thinkers beyond Bereiter have noted these contrasting modes of engagement related to one's aim. It bears repeating that as opposed to most contrasts provided, it usually is done with the intention of labeling one as "good" and the

other as "bad". For the purposes of this research this type of good/bad dichotomy is not useful. Instead this contrast should be considered more like contrasting a spoon and a fork, both important tools yet with very different application. Bereiter distinguishes design mode from belief mode, the former mode engages the participant in a creative and generative manner while the latter engages the participant in an analytical and perspective seeking manner. Cohen (1995) in his article, *Argument is War... and War is Hell: Philosophy, Education, and Metaphors for Argumentation* seeks to explain two different kinds of argumentation which are roughly comparable in character to Bereiter's two modes, design and belief. In describing his noncritical approach Cohen states:

> *From the perspective provided by thinking of arguments along the speech-act lines just presented, reading looks a lot like arguing with the author. Readers need to argue with, meaning alongside, the author rather than with, meaning against, the author, in order to enhance whatever it is that the text is saying, showing, or doing. (p. 182)*

This sense of being part of, "alongside" that is, aligned or within a structure rather than outside or "against" it is exemplified by Stephen Covey's fifth principle of highly effective people: "Seek first to understand, then to be understood." He describes understanding-seeking listening as getting "… inside another person's frame of reference. You look out through it, you see the world the way they see the world, you understand their paradigm, you understand how they feel" (p. 240), sounding similar to design mode. He contrasts this understanding-seeking mode to the mode of persuasion that is, the perspective-taking used in argumentation. Dr. Betty Edwards, in her seminal book, *Drawing on the right side of the brain* (1979) taught non-artists to draw realistic-looking images. Unique to her approach was providing a series of activities that cause a sense of

tedium in the dominant cognitive mode in non-artists and after a period of time this

dominant mode relinquishes control to the hemisphere equipped for such tasks. Through

these tasks the student becomes able to identify this "right brain mode" and more easily

make this mode switch when wanting to draw. Lending experimental support to Edwards

model, authors Huang et al. (2013) cite Edwards book in their historical overview of the

concept of artistic creativity and hemispheric dominance. They conclude that,

> *"these data suggest that the left frontal lobe may inhibit the right hemisphere*
> *during figural creative thinking in normal people. Moreover, removal of this*
> *inhibition by practicing artistry or through specific damage to the left frontal*
> *lobe may facilitate the emergence of artistic creativity" (p. 2724).*

Edwards (1989, pp. 34–37) describes the cognitive mode involved in drawing as not

requiring a basis of reason or fact; a willingness to suspend judgment, and sense where

things are, in a spatial sense, in relation to other things and how the parts go together to

form a whole. Further, she describes it as intuitive, making leaps of insight, often based

on incomplete patterns, hunches, feelings, or visual images. It is holistic, seeing the

whole things all at once, perceiving the overall patterns and structures, leading to

divergent conclusions. It is not unreasonable that this cognitive mode described by

Edwards is the, seeking-to-understand mode of Covey and the arguing-alongside mode of

Cohen and the design mode described by Bereiter and Scardamalia.

It is argued that complex problems of understanding, those especially useful in

theory development, are examples of "Wicked problems" (Leinonen & Durall, 2014).

Wicked does not refer to the problem being malicious, it instead denotes its resistance to

resolution. Pertinent characteristics of a wicked problem (Conklin, 2005) include: the

problem is not understood until after the formulation of a solution, (Dorst, 2006) wicked

problems have no "stopping rule" and solutions to wicked problems are not right or

wrong, just better or worse (p.7). Solving wicked problems is clearly the purview of

design mode thinking which attends to the structure of a system. Echoing this distinction

between design mode and belief mode, Boland & Collopy's (2004) research converged

on two discrete perspectives, calling them the "Design Attitude" and the "Decision

Attitude" the latter reasonably corresponding to the "substantiating" view described

below.

Owen, in his article on "design thinking" (2007) provides structure to the

discussion on design thinking and its use in different professions. While his description of

the work of designers does inform this discussion and will be mentioned in a following

section, his description of science is consistent with Bereiter's belief mode description of

science activity. This description is based on an unfortunate view of the nature of science.

He describes science thinking as focusing on measuring dichotomies of true/false,

correct/incorrect, complete/incomplete, provable/unprovable (p. 21). This description,

along with Cohen's description of "arguing against" appear to be consistent with an

essential practice of science: argumentation. The purpose of this practice is to engage

with the "correctness" of information. It is argued then, when engaging with the belief

worthiness of information, a specific cognitive mode is actuated. In this mode one relates

ideas, claims, reasons, arguments, observations to an external position, and is not

"alongside" or "within its own frame of reference". For example, when deciding on the

model of computer to buy one considers measurements of the computer system in reference to an external rubric. Likewise, when considering between three competing models, one can consider the precision by which each model predicts the results of an external event, external meaning not part of the structure of the model, but the relationship between the structure and a phenomenon "outside" of it.

The characteristics described in the preceding paragraphs are summarized in the next paragraph and are reported as a chart in Table 4.4. In the chart, the characteristics are developed and organized in subgroups in terms of three foundational types of problems that, as a community, scientists address: problems of relevance, problems of methodology and problems of understanding. While the taxonomy of problems evolved over the remainder of the inquiry these problem types continue in importance through the end.

Design mode is the mode engaged when: solving theoretical problems which are considered to be "wicked" design problems; "arguing alongside", i.e., within a system; listening in order to understand another person's perspectives relative to that person's own framework of values and beliefs and experiences; and engaged in design thinking which attends to the qualities of a design, i.e., a structure adapted to a purpose. Briefly summarized, the essence of design mode is attending to the qualities of the structural relationships from within the perspective of the system. The following ideas informed a conception of Bereiter and Scardamalia's belief mode is the mode of persuasion which is concerned with the perspective of correctness or truth, it is important in a decision

attitude which assesses the worthiness of something based on its relationship to external criteria, it uses dichotomies of true/false, correct/incorrect, and other tools of analysis. It is the mode availed when "arguing against" where one does not inhabit the others framework, i.e., is outside the others perspective. In conclusion, belief mode is the mode engaged when something is to be evaluated relative to "outside criteria", said in another way, when one works with a knowledge object, considering it a discrete, static object to be evaluated relative to exterior criteria. This mode is required in science when considering the truth that is, belief-worthiness of a knowledge object. The information presented in Table 4.4 is based on the literature-based provided in this section as well as through coding student contributions as described in the following section. Table 4.4 presents these ideas in the context of solving problems of relevance, ways of knowing and understanding.

Table 4.4 Distinguishing between cognitive aspects of design versus belief modes by problem type.

Problem-Type	Mode of Solving Specific Problem Type	
	Design Mode **Improving system qualities**	**Belief Mode** **Substantiating a position**
"Problem of Understanding" Problems related to explaining a natural phenomenon	Activity seeks to understand or explain: • problems of explanation/ understanding And does this by: • Designing good or "the best" explanations or mechanisms.	Activity seeks to create, increase or decrease • The belief-worthiness of an explanation And does this by: • Arguing for or against claims of explanatory power.
"Problem of relevance" Problems related to the real-world value of the knowledge created:	Activity seeks to understand or explain: • Problems of idea's relative value or application. • How well knowledge objects solve real world problems. • Peoples' or communities' context: their values, beliefs and knowledge And does this by: • Designing (a context-specific) solution to a real-world problem using the knowledge created.	Activity seeks to create, inc. or dec.: • Value of the application of an explanation or problem • Coalition building around or against applications of solutions to real world problem. And does this by: • Arguing for or against a claim of the value of the application
"Problem of Ways-of-knowing" Problems related to how we ought to make knowledge:	Activity seeks to understand or explain: • Problems of frame? • How knowledge came to be • People's epistemic framework (e.g.: "Why do you believe 'what science says'?") And does this by: • Designing A useful, good, or 'the best' epistemic system. • Ask, "Why do you believe"...	Activity seeks to create, inc. or dec.: • the belief-worthiness of an epistemic framework • Claims of (un)worthiness of an epistemic framework And does this by: • Arguing for or against claims of value of a way of knowing, i.e., methods.

4.2.3.2 Coevolution of coding template and Design/Belief mode model

In order to understand and evaluate Bereiter and Scardamalia's idea that design mode is of paramount importance in Knowledge Building discourse, student contributions were coded in terms of their epistemic aim. In essence, the coding sought to determine if the students' contributions were aimed at developing a relationship to knowledge in terms of its design or if the contributions were aimed at developing a relationship to knowledge in terms of its truth value. This coding and the concurrent development of the design/belief mode model were theoretically fruitful and ended in developing the initial coding template and thereby brought about the end of the exploratory Phase 1 of this research, transitioning to Phase 2. Gee's discourse analysis approach was used in this coding, its use provided a more substantial understanding of a students' epistemic aims in terms of these two modes.

In the process of inferring and coding a student's epistemic aim, the developing design/belief mode model was often challenged and required constant revisions in its design. The coevolution of the model and the coding of student contributions were further aided by my personal experience with Edwards (1979) work on cognitive mode awareness. This awareness provided important insight into the inference of the student's epistemic aim as well as to the design of the design mode/belief mode model.

As summarized in Table 4.4 the distinct type of cognition engaged during design mode activity was conceptualized as "system-referenced" as there was a sense of being within the system or framework during this engagement, "alongside" the idea as opposed to "outside" the idea. The distinct type of cognition engaged during belief mode work

was conceptualized as "position-referenced" as there is a sense of one being outside the system and referencing ones understanding of the system from outside of it. As shown in section 4.4.1.1, Gee's discourse analysis provided important insight into the world-building occurring in the discourse, aiding the inference of aim of the mode. To further facilitate this process, a "codebook" with key-words was developed to aid in this inference and is shown in Appendix B.

During the final work in Phase 1 of the research, considering types of problem spaces in which students engaged grew in importance. Two types of problems had been considered: "problems of understanding" which are engaged in design mode and, "problems of belief" which are engaged in belief mode as established by Bereiter and Scardamalia (2003). These ideas were extended to problems of relevance and problems of ways of knowing. Problems of relevance are entertained when a student asks, "Why is this idea important?" Problems of determining good ways to investigate, to come to know reliable knowledge are central to science and Knowledge Building and come up when curiosity of how an idea had come to be believed or known, or concerns of the validity of a claim appear. The idea of different problem spaces of inquiry became central in the last phase of inquiry. The initial coding template shown in Figure 4.4 presents how the themes of design/belief modes, aim of solving specific problem types and the knowledge improvement cycle were hypothesized to be related at the start of the final phase, Phase 2, of this inquiry. Note that a few terms were updated in the template presented Figure 4.4 in order to be consistent with the terms of the same concept that were used at the end

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of this research. Through the hybrid methods that were integrated through template

analysis, during steps five and six of template analysis, this descriptive structure was

transformed significantly.

4.3 Phase 2: Elaborating and transforming the coding-structure / descriptive-theory

Phase 2 of the inquiry commenced once the initial coding template (Figure 4.4)

had been created. This phase involved the two iterative, complementary stages of the

knowledge improvement cycle but applied to the hybrid philosophical – empirical

version of template analysis as was introduced in section 4.1.2 and further developed in

section 4.3.1. The iterative cycle included coding, which sought to improve the coding

system by elaboration, and when that fails significantly, abducing, which sought to

improve the coding system through transformation. These stages could be considered to

have similarities with Kuhn's (1970) "puzzle-solving", that is, normal, and

"revolutionary" stages of science, respectively. This process is described textually in the

following paragraphs and illustrated diagrammatically in Figure 4.5. The aim of this

process was to produce a coding hierarchy that fit all of the data, and as a classificational

descriptive theory, that was consistent with the ideas considered promising to provide

understanding of Knowledge Building.
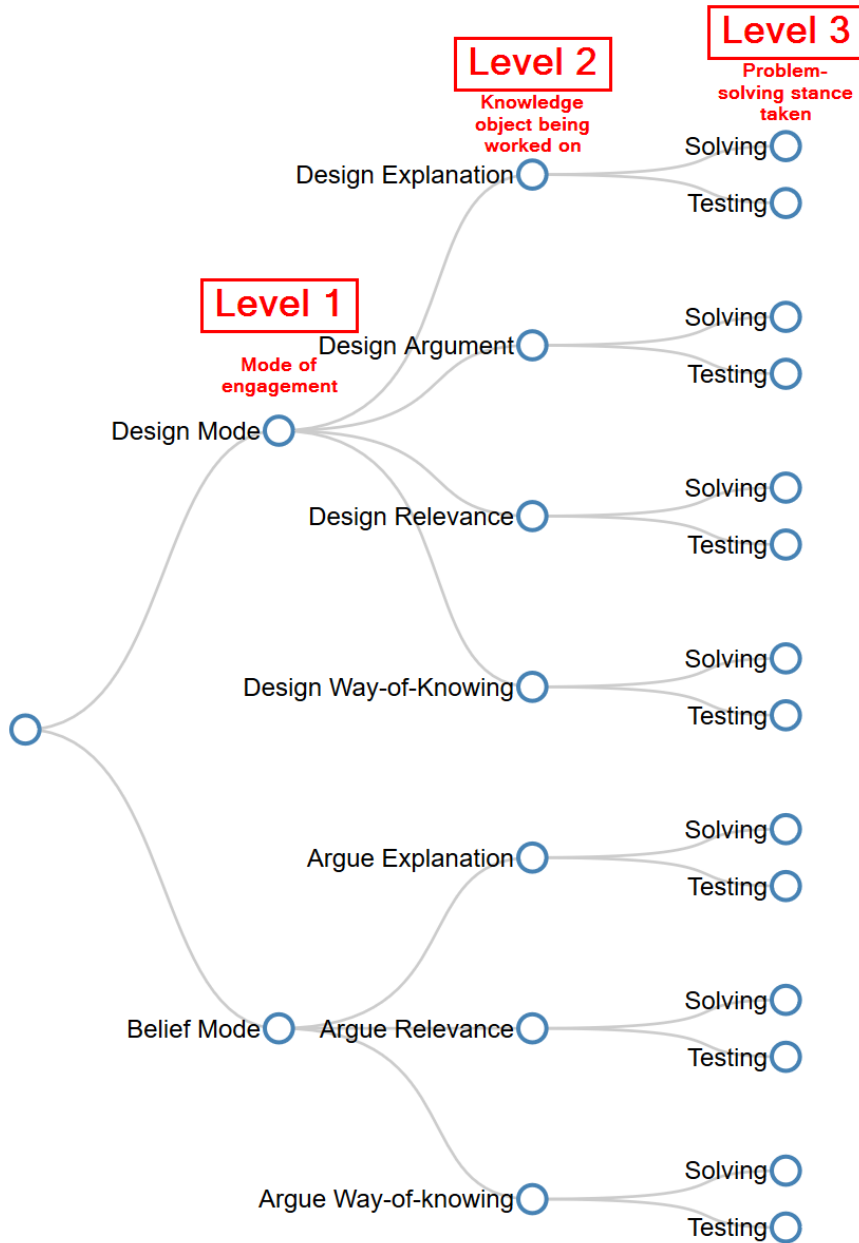
Figure 4.4 Initial coding template with three levels

4.3.1 The hybrid inquiry process in terms of template analysis

Template analysis is typically used to elaborate or test an existent theory.

However, RQ3: "*What is a descriptive theory of Knowledge Building in the science class*

in terms of: types of problems, epistemic and social moves that take into account the

ideas of design and belief mode and the need to develop consensus around developing

theories, and problem-solving using specific types of knowledge objects?", sought to

create a descriptive theory from promising theories. Therefore, a form of template

analysis that incorporated hybrid philosophical-empirical methods was called for. In the

research on RQ3, when the a priori coding templates were shown through empirical

methods to be insufficient, philosophical methods that availed the set of identified

promising theories were used to develop an improved coding template.

Initially a coding template, i.e., a descriptive theory, was designed based on what

was learned both through the exploratory coding and reflective engagement with the

promising theories. Using the *a priori* coding template, a small part of the data was

coded: that is, the template was applied to the contributions, one at a time, starting from

the first contribution in Big Q1. The results of coding a single contribution, i.e., a coding

episode, had two possible outcomes:

1) the template adequately fit the contribution and the code was assigned to the
   contribution;
2) the template was inadequate to fit the contribution. In this case, there were
   two possible outcomes:
   a. a sibling category was added to the framework allowing for
      successful coding of the contribution and code was assigned to the
      contribution. This was followed with a new coding episode.
   b. no sibling category was able to be deduced and therefore the
      framework had to be transformed through abductive methods.

As the initial coding template had been already developed through extensive exploratory

coding aided by promising theories as described in Phase 1, the results of coding the

contributions in Big Q1 were described by outcomes 1) and 2) a. However, as further

contributions were engaged in Big Q2 and beyond, the outcome described by 2) b above was encountered. This involved reconsidering the ideas related to the phenomenon being investigated and the epistemic aims of the research. Through reading, discussing and individual reflection guided by abductive processes, along with the insights gained through the empirical coding, the problem space the problem space developed. Invariably, in an, "aha!" moment, the ideas in the themes were seen in a new way leading to the construction of an improved coding template. This improved framework could typically fit all previously coded contributions and the challenging ones which the previous coding system had been unable to accommodate. Once again, using the new template, coding would commence on the first contribution in Big Q1, proceeding through the contributions as before. It would again end when the new version could not be successfully elaborated, demanding a transformed template. This general description describes the inquiry process throughout Phase 2, ending when all contributions were satisfactorily categorized and theory could no longer suggest any improvements to test. Together these complementary activities of empirical and philosophical inquiry were iteratively performed and allowed for the development of a creative yet credible descriptive theory.

Just as the template analysis method can be represented by the KIC (Figure 4.2), so too can the hybrid version of template analysis be represented. In addition to representing the problem-solving as a single cycle, Figure 4.5 represents the Solving and Testing activities as sub-iterative processes. The iterative cycle on the left side of this

representation, the Solving activity shows the creative synthesis of a coding template arising from theories that have been posited to be important in Knowledge Building. The cycle on the right describes the process of validation and discovering of new problems through the empirical testing of the data.
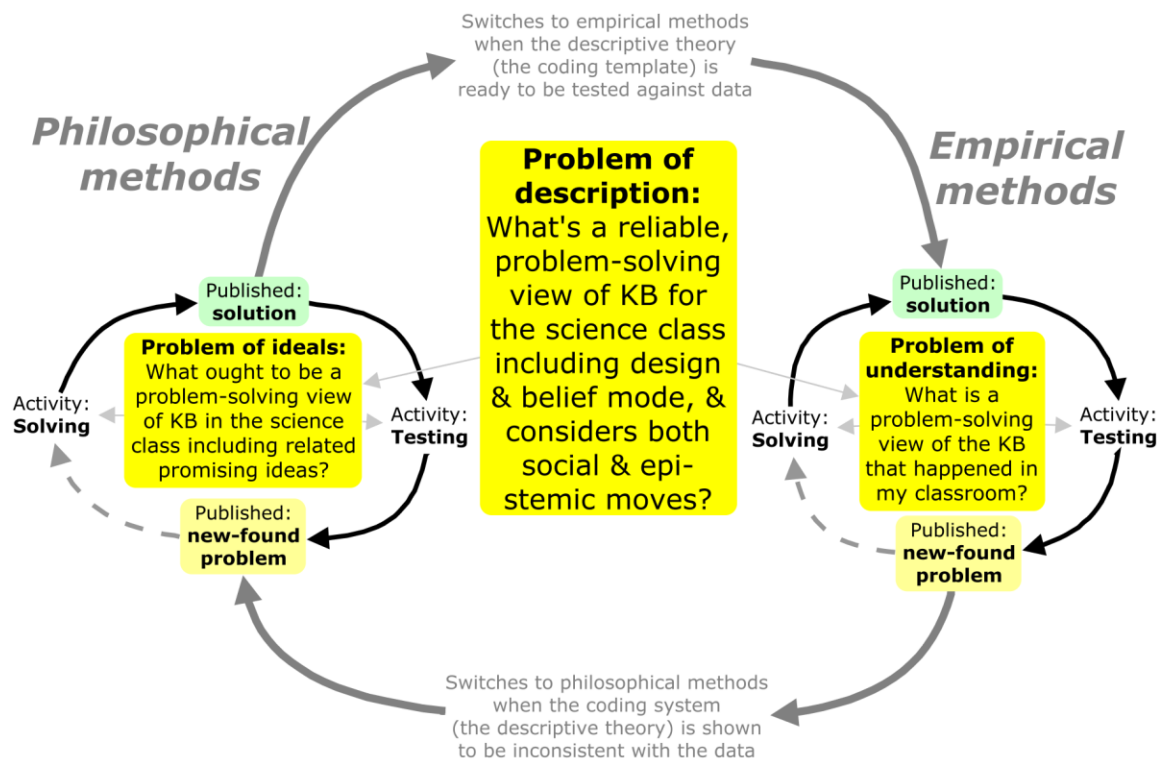
Figure 4.5. Visual representation of hybrid methods afforded by template analysis methods.

4.3.2 Final descriptive theory is explained analytically

The final coding system, that is the descriptive theory, is explained in two ways. First, the structure of the descriptive theory is explained analytically with visuals and text in the current section. Second, in section 4.4, the descriptive theory is explained using data, i.e., the student comments as examples, both illustrate the meaning of the categories and themes through contributions and also display some empirical challenges

encountered in the coding. The "Advance Theory" branch with its four levels of hierarchy and sample student contributions can be seen in Figure 4.12. This structure is variously referred to as a descriptive theory, framework, hierarchy, template or taxonomy.

4.3.2.1 Level 1: Domain of engagement, i.e., Problem space

Level 1 of the taxonomy is displayed in Figure 4.6. Level 1 categorized the four essential problem spaces, that is, domains, in which students doing Knowledge Building will need to work. The four domains will be briefly described. As developed in chapter 2, working in the first domain, Advance Theory problem space is commonly considered the primary responsibility of scientists. However, in order to accomplish the mission of advancing theory, students doing Knowledge Building in science class, and it is suggested that scientists as well, must also engage in three problem domains distinct from advancing theory. The second domain, Building Relevance, is entered when there is need to build the relevance of the theories being worked upon. The question of relevance is related to the usefulness of the theory to solve important societal or scientific problems. It addresses the question of, "Why should one care about this theory?" and is directly connected to questions of values. The third domain, Developing Ways of Knowing is concerned with the development of methods and methodology appropriate to creating knowledge in one's field. This is applicable to both professional scientists but especially important for students in a KB community. While some problems related to ways of knowing get solved at a basic level, as a field develops and problems deepen there is an

ongoing need to consider, curate, improve and create new methods and methodologies. The fourth domain, Improve Process, is engaged when addressing problems of classroom Knowledge Building discourse, from spelling or social norms to assessing the class' progress in knowledge improvement.
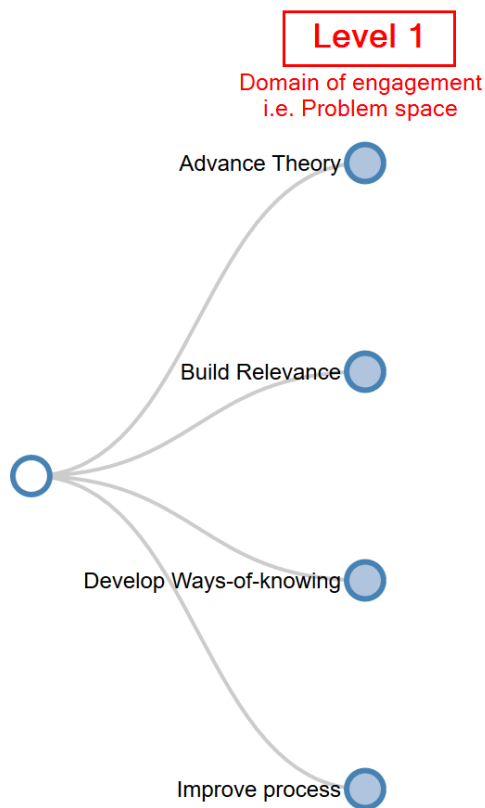
Figure 4.6. Level 1 of coding framework.

4.3.2.2 Level 2: Aim of engagement

Level 2 of the coding framework has been revealed in Figure 4.7. Each Level 1 problem space has three corresponding Level 2 codes describing the three overarching "Aims of Engagement" within the particular domain. These aims are considered to recruit distinct types of cognitive effort as introduced in section 4.2.1.2 and extensively

developed in section 4.2.3. Each aim corresponds to a distinct type of activity: designing, substantiating or building community. The first Aim of engagement, Design [the knowledge object], involves designing. "Designing" engages with the object of activity from a "within the system" perspective. In this situation, "within the system" refers to the internal structure of the knowledge object itself and its relationships to other knowledge objects with which it is expected to be used. This aim seeks to improve the design of the knowledge object and leads to the type of activity described by Bereiter and Scardamalia (2003) as "design mode" activity. The second Aim of engagement, Substantiating [the knowledge object], seeks to influence the belief worthiness of an object and leads to what Bereiter and Scardamalia described as, "belief mode" activity. "Substantiating" engages with the object of activity from an, "outside the system" perspective. That is to say, one is standing *outside* of the system of knowledge objects defined above as, "within the system", evaluating that system and its parts relative to a position or positions outside that "internal system". Only from this external position do the concepts of correctness or truth have meaning. Therefore, the process of substantiating requires this external position and it is argued in section 4.2.3 to engage a different kind of cognition than that engaged when designing. The third Aim of engagement, Building Community Around [the knowledge objects], involves consensus-building. Building community engages with the object of activity, affiliation with a specific knowledge object, from a political point of view, seeking to influence people's affiliation to the knowledge object under consideration such as an explanation. In the context of the study, the community in which

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the consensus building was considered to be the Knowledge Building community. When this aim is pursued in communities outside the Knowledge Building community in which it was developed, scientific argumentation plays a significantly larger role (Latour, 1987; Latour & Woolgar, 2013). This would become more significant when there are interactions between different Knowledge Building classrooms.

As shown in Figure 4.7, the three aims in each domain are analogous, differing due to the unique type of knowledge object developed in the domain. The aims can be expressed generically as: designing the object, substantiating the object or building community around the object. To understand how the three generic aims are instantiated in each domain one must know the unique type of knowledge object developed in each domain. The knowledge object worked upon in the Advancing Theory domain is an explanation, i.e., theory. In the Building Relevance domain, the knowledge object would be an expression of the relevance of the theory. In the third domain, Develop Ways of Knowing, the knowledge object developed would be research methods needed for inquiry into a particular theory that is being advanced. The knowledge object developed in the last domain, Improve Process, would be a statement about the process. In conclusion, while the three aims are analogous in each domain, their exact instantiation is dependent upon the type of knowledge object relevant to the domain in which the knowledge work is done.
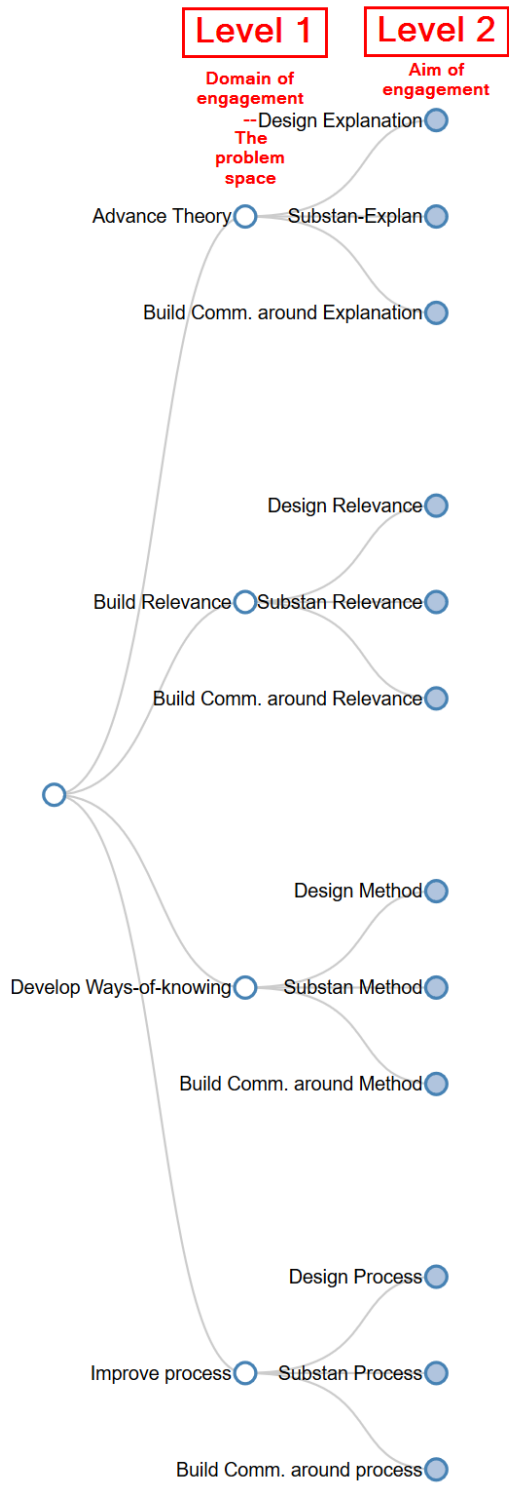
Figure 4.7. Levels 1 & 2 of descriptive theory.

4.3.2.3 Level 3: Problem-solving stance

In Figure 4.8, Level 3 of the coding framework has been revealed for the Advance Theory domain. This level of the hierarchy incorporated the knowledge improvement cycle (KIC) which was extensively developed in chapter 2. The KIC models Solving and Testing as the opposing activities in the problem-solving cycle. As described in the next section, when contributing from a Solving stance, a declarative statement such as a fact, explanation, claim etc. are produced, while advanced from a Testing stance, a question or problem statement is produced. Because one engages in problem-solving when designing, substantiating and building communities around a knowledge object, it follows that these two stances similarly stem from each of the three aims in each of the four problem spaces and indeed that is shown in the full framework displayed in Figure 4.10.
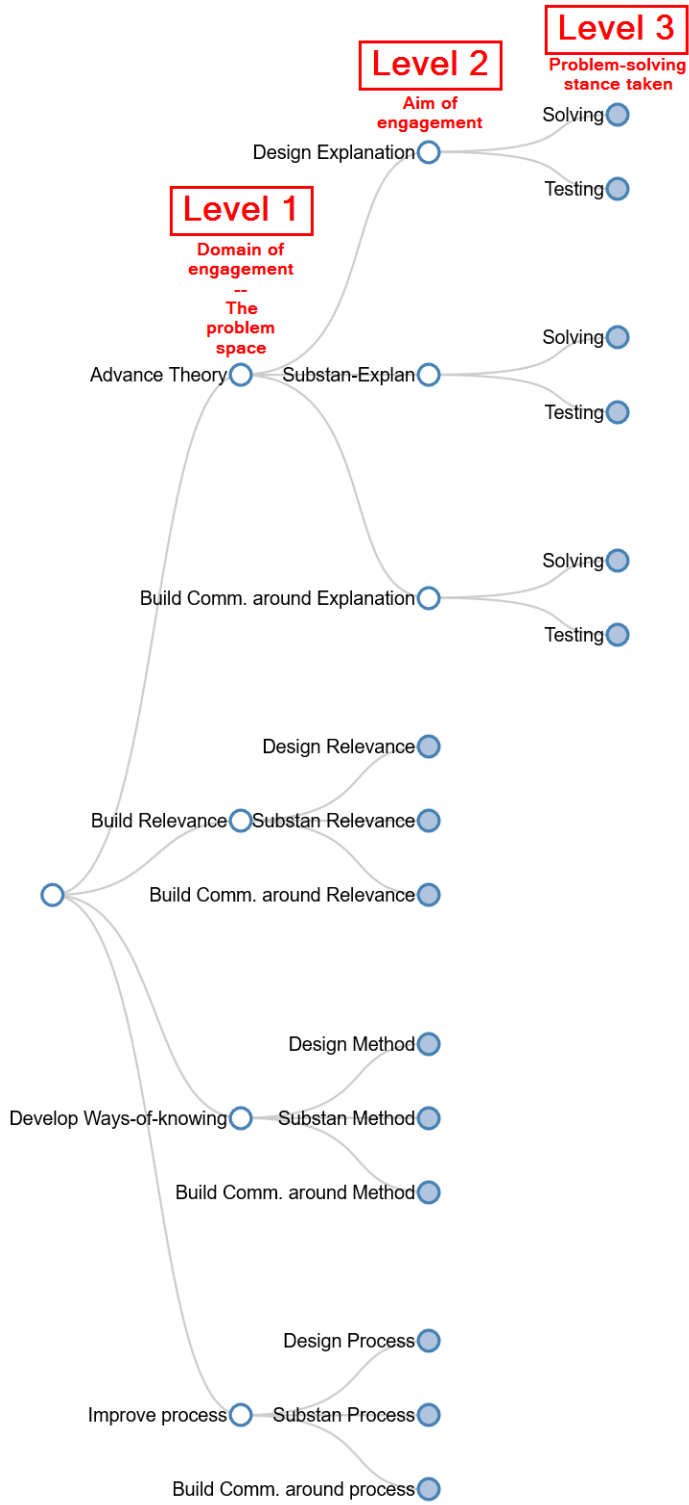
Figure 4.8. The first 3 levels of the coding framework is revealed for the "Advance Theory" branch.

4.3.2.4 Level 4: Knowledge type, i.e., discourse move

The final level of coding, Level 4, named the type of knowledge the student

employed in their contribution to build knowledge. The categories in this level were

suggested by the "progressive inquiry" set of knowledge types provided by FLE4, with

two exceptions that will be described. In Figure 4.9, the Level 4 codes have been revealed

for only the Design Explanation Aim of engagement in the Advance Theory Domain. As

seen in this figure, there are three knowledge types, i.e., general discourse moves, for the

Solving stance and two knowledge types for the Testing stance.

The three knowledge types for Solving label the declarative moves where one is

offering some kind of information pertinent to the Knowledge Building dialogue. From

the names such as, "My Explanation" or "Source-based Explanation" it might be inferred

that these knowledge type (KT) codes were only applied to a contribution that provides

an explanation. However, these KT's were used to tag any type of declarative statement

meant to advance the development of an explanation such as facts, conjectures and

opinions as well as fully developed explanations. As described in chapter 2, the essential

difference between the KT's "My Explanation" and "Source-based Explanation" is their

different claim to authority. The "My Explanation" KT is applied to declarative

statements where no special claim to authority beyond the student authoring the

contribution is made. These contributions are offered as intuitive answers, opinions,

personal values and affiliations. However, applying the "Source-based Explanation" KT a

declarative contribution implies that it was based on information obtained from an

external source considered to be authoritative. This KT is only applied to contribution

that cite a source that the author considers authoritative and has the possibility of being checked. The third KT from the Solving stance, "Summary", is applied to contributions that aim to summarize information from different contributions and authors into a single post to provide a substantial answer to an important question.

In the progressive inquiry set of KT's provided in FLE4 there was another KT that would have been classified as coming from a Solving stance: "Evaluation of the Process". As described in Appendix D, through the inquiry process that occurred in Phase 2, the Evaluation of the Process KT was seen to be better conceived of as an entire problem domain and not as a discourse move, i.e., KT. As it is a Level 1 category it is described in section 4.3.2.1.

It can be seen that there are two KT's from the Testing stance: Problem and Question. This is the other difference from the the progressive inquiry set of knowledge types where only one KT was provided, the combined, Problem-Question. However, as argued in chapter 2, problems and questions refer to different types of knowledge objects that serve different epistemic roles in Knowledge Building. Furthermore, creating a Problem KT is a descriptive task requiring one to identify and describe the essence of a problem, yet creating a Question KT requires an agent to develop a question that will interrogate some epistemic feature of the problem.

This set of five KT's: three from the Solving stance and two from the Testing stance are essentially repeated for the three different Aims of engagement in the Advance Theory domain as seen in Figure 4.12. However, while the set of two knowledge types

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extended from the Testing stance were identical, Problem and Question, the set of three "Solving" knowledge types were analogous, the specific knowledge type corresponded to the particular the Aim of engagement. For example, when one is aiming to design an explanation, a KT of "My Explanation" or "Source-based Explanation" might be given but if one is aiming to substantiate or likewise unsubstantiated an explanation, the KT offered might be a "My Argument" or a "Source-based Argument". And just as described in the second paragraph in this section where a "My *Explanation*" was used to code for a fact, conjecture and opinion, a "My Argument" can be used to code parts of an argument such as a claim, evidence or reasoning. In the third aim of "Build Community around Explanation" the corresponding KT's would be "My Affiliation" or "Source-based Affiliation". Thus, the basic set of 5 KT's serve as a template which is appropriately instantiated for each of the three aims within a problem domain, although the KT's from the Testing stance are the same for each aim.

In the same manner that the set of three aims of engagement are adapted to each of the four domains as described in section 4.3.2.2, the three sets of five KT's are adapted to each domain as well. This is shown in the full framework illustrated in Figure 4.10. For example, in each problem domain there is a, "Design…" Aim of engagement adapted to the type of knowledge object that is produced in that particular Domaine: "Design Explanation", "Design Relevance", "Design Method" and "Design Process". In the same sense, the Solving KT's for each of the three Aims of engagement is likewise adapted. For example, the KT corresponding to the design Aim of engagement in each domain

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would be adapted to the type of knowledge object being developed. Therefore, in the Advance Theory domain there was a "My Explanation" KT, in the Build Relevance domain there was a "My Relevance Statement", in the Develop Ways of Knowing domain there is a, "My Method" and finally in the Improve Process domain there was a "My Process Statement". Likewise, if the aim is to substantiate the knowledge object being developed, they were: "My Argument", "My Relevance Argument", "My Method Argument" and "My Process Argument". This pattern continues and can be seen in Figure 4.10. As described above, the knowledge types stemming from the Testing stance were not adapted and thus were always Problem and Question.
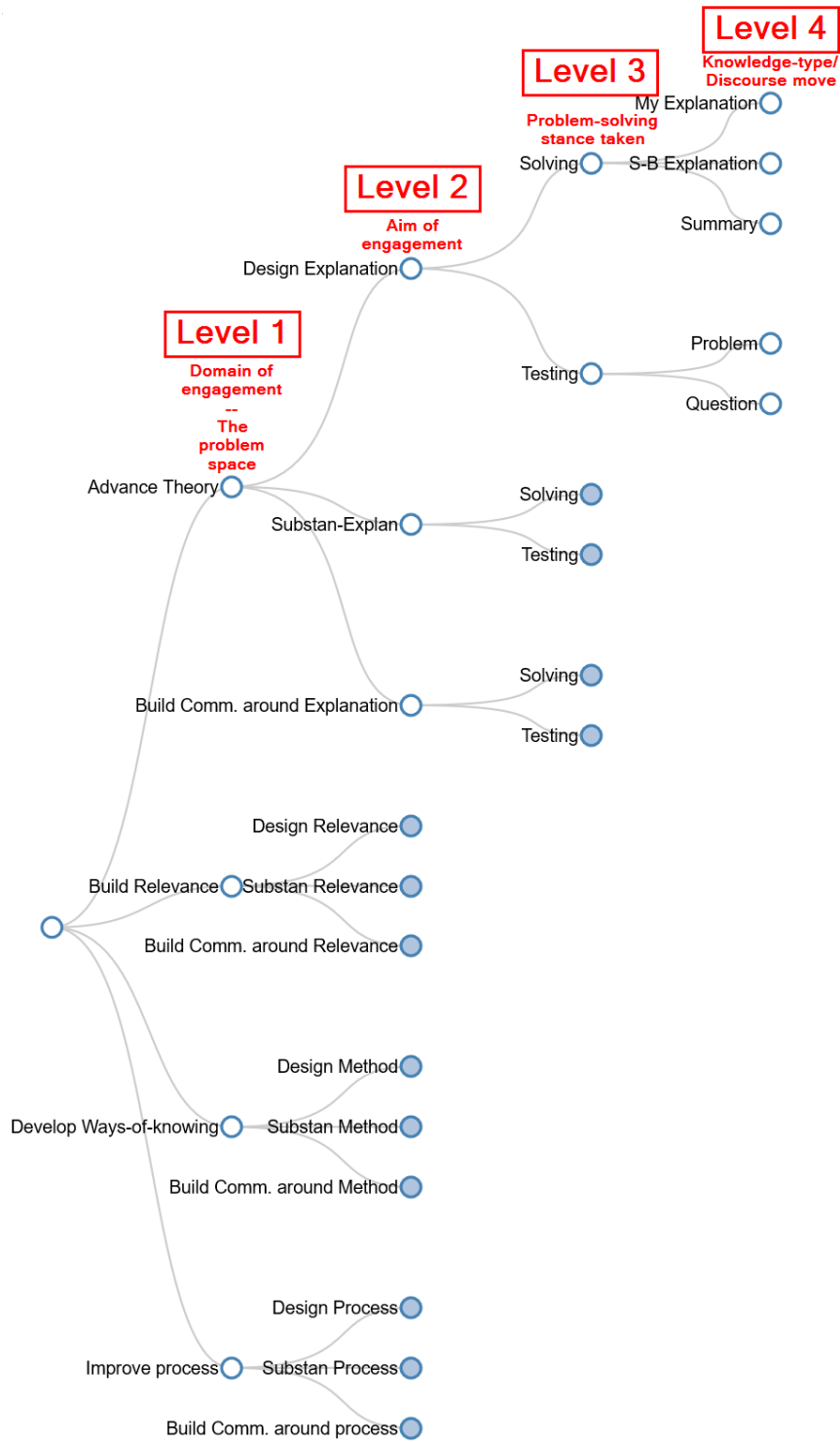
Figure 4.9. Representative parts of all four levels of code are shown.

4.4 Empirical coding illustrated through contributions

The third product developed in this research, a descriptive theory of a problem-solving view of Knowledge Building in a science classroom, was developed as the coding framework of the student contributions in FLE4. It was explained analytically in the previous section. In this section the framework, that is the coding system, will be illustrated through coded student contributions. The coding method used a hybrid philosophical-empirical adaptation of template analysis as described in section 4.1.2.

The final version of the coding system is displayed in Figure 4.10. As the aim of this research was to discover what Knowledge Building *ought* to be, the final coding system expresses more than the data that was generated by students in their Knowledge Building work. Therefore, there are a number of codes in that system that were not evident in the data set. The codes shown in Figure 4.10 that are followed by a checkmark were codes that were represented in the data set.

There was a total of 207 comments in the data set that were coded. Of these, 150 were coded to be doing knowledge work in the Advance Theory domain (Figure 4.11). As this domain was the most richly represented in the data, it will be used to illustrate how student contributions were coded in the final coding structure. This is presented below.
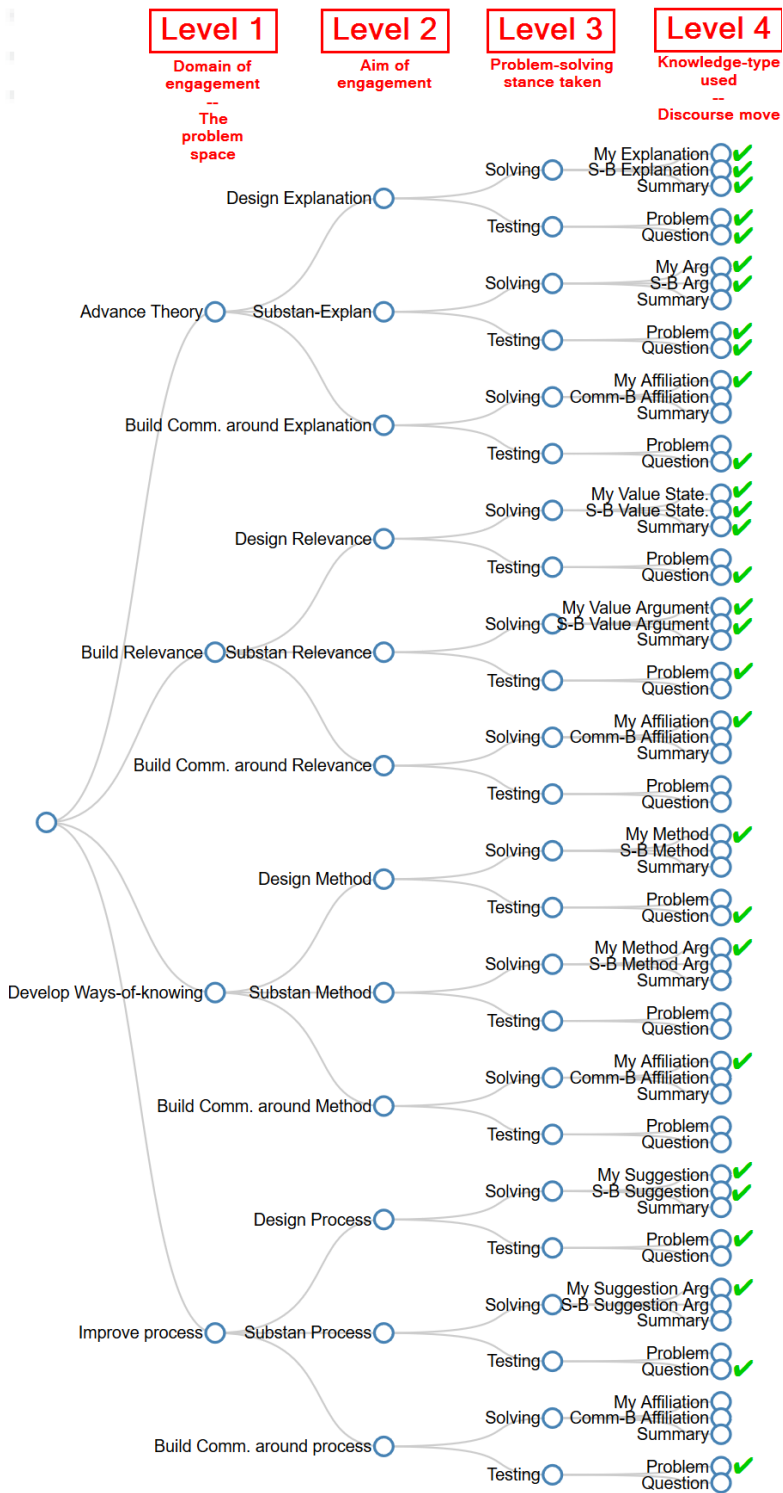
Figure 4.10. Full descriptive theory. Codes from data marked with checkmarks. (S-B = Source-based)
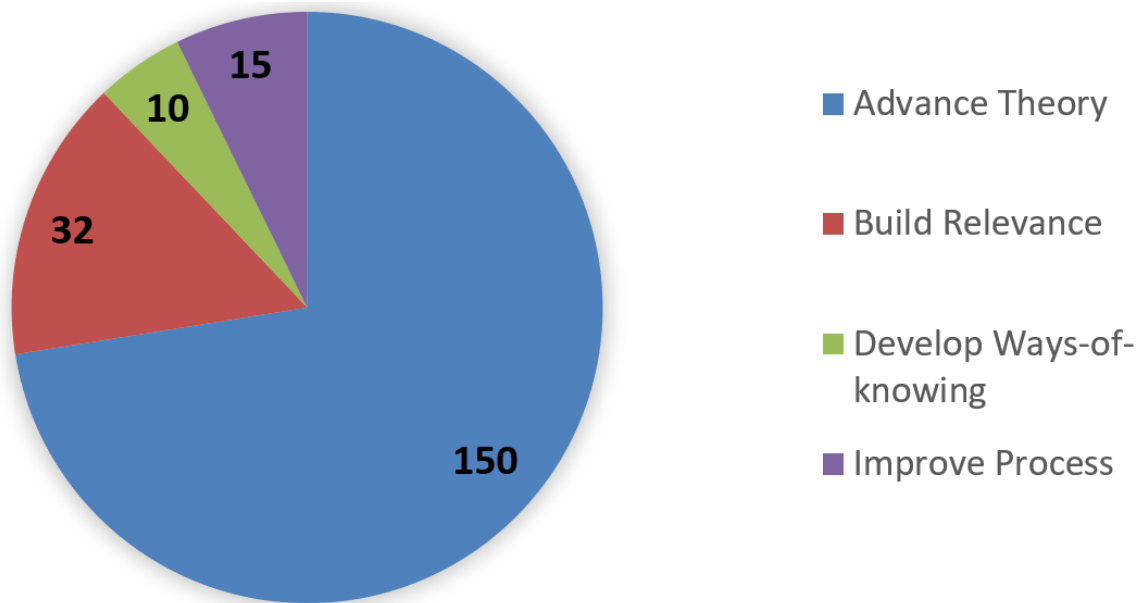
Figure 4.11 Count of student contributions in each of the four domains.

4.4.1 Illustrations of five codes with "Design Explanations" aim

In the following five subsections, the three Solving KT codes and two Testing KT

codes are illustrated through student examples. This section relies on the detailed

description of the four hierarchical levels and their elements provided in section 4.3.2.

See Figure 4.12 for the Advance Theory branch of the coding system with representative

student contributions.

Level 4
Knowledge-type/
Discourse move

Level 3
Problem-solving
stance taken

Level 2
Aim of
engagement

Level 1
Domain of
engagement
--
The
problem
space

My Explanation — i think... humans were made of monkeys because of there body structure

S-B Explanation — humans and chimpanzees share a common ancestor but they don't come from each other i got my research from http://www.pbs.org/wgbh/nova/evolution/our-family-tree.html

Summary — "Indeed, and that's why generations differ because the offspring are only from those who survived to reproduce. Those who have offspring are those most adapted to the environment of that particular population so far."

Problem — "I don't remember this, perhaps I missed that lesson…."

Question — talk more about how they migrated?

My Argument — "I don't think that they did, that's a common misunderstanding of evolution or so I hear. Try thinking of it more like humans and apes had a common ancestor, of course what you believe is up to you."

S-B Argument — Well I go to the church and I read the blible, and the bible says that and I believe it.

Summary — **Code generated by theory**

Problem — not everyone believes in what scientists tell us.

Question — what is the evidence that you have encountered that makes you believe this

My Affiliation — "Even though My explnation was diffrent I agree more to your explnation on how Darwin's work got noticed"

Comm-B Affiliation — **Code generated by theory**

Summary — **Code generated by theory**

Problem — **Code generated by theory**

Question — what was your question about?

Figure 4.12 Student contributions illustrating codes for "Advance Theory" branch.

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4.4.1.1 Code: Advance Theory, Design Explanation, Solving, My Explanation

The first student contribution was coded as: "Advance Theory-- Design Explanation—Solving-- My Explanation" as shown in the title of this section. The structure of the code was given as: Domain-- Aim of engagement-- Stance taken-- Knowledge type. Expressed as a sentence, the code was applied to contributions that were: seeking to: "Advance Theory"… in design mode… from a "Solving" stance… by providing a "My Explanation".

The following contribution, which received this code was made in the Big Q1 which asked, "From what did humans evolve?" The following student contribution, like all in this section, are copy and pasted exactly as they were online. This precision of representation is meant to provide readers of this research with the actual data. As per Gee (2011a), punctuation, capitalization, clause construction and order as well as word choice and more are essential tools of discursive world building. The student wrote:

"i think…humans were made of monkeys because of there body structure"

This contribution was coded as seeking to Advance Theory as it was attempting to explain why it was reasonable to think that humans are related to monkeys. Next, it was necessary to infer the Aim of engagement of the contribution. Of the three possible in the framework: designing, substantiating or building community around the knowledge object, it was inferred to be an aim of "Design Explanation" for the following reasons. In this contribution, there was no compelling indicator that the contribution was aiming to,

"Build Community around the Explanation", and therefore that aim was not applied to this contribution. The two remaining aims, designing and substantiating, are differentiated with the design mode/belief mode contrast developed in section 4.2.3. At first it was not as evident whether this contribution was meant to develop understanding and therefore engage through design mode, or if it was meant to substantiate an explanation and therefore engage through belief or critical mode. According to the definitions of argument and of explanation provided by Osborne and Patterson (2011), this contribution would be considered an argument because of its logical structure: it contains a well-established premise, i.e., an unquestioned assertion, that of the similarities in monkey and human structure, which was being used to support what would then be the less than certain claim, that humans evolved from monkeys. And as an argument, it would have been made with the aim of substantiating, that is influencing, the claim's belief-worthiness. However, as they argued, even in the professional science education community it is not uncommon that the practices of argumentation and explanation are conflated. Therefore, in the student community it is highly unlikely that students would consistently apply the logical structures of argumentation and explanation. For this reason, the logical structure of the contributions was not considered sufficient to determine their aim. Therefore, other criteria were required to determine the aim of the epistemic work intended by students with their contribution.

For this research, distinguishing between the aims of "designing" and "substantiating" involved determining if the contribution worked toward increasing

understanding or towards influencing the belief-worthiness of the knowledge object. Neither the effectiveness, sophistication nor correctness of the attempt was taken into account in this analysis to determine the student's aim of engagement, just the student's inferred epistemic intention. The contribution serving as an example in this section was a root level post, in other words, it was not in response to any other student's post, but instead was a response to the big question, and therefore, no cues were provided by its relation to another contribution. Through the development of the coding system, it was concluded that to indicate an aim of substantiating, an indication that the student, through his or her contribution, made some effort towards increasing or decreasing the belief-worthiness of a position. If no indication of this was found then the contribution was interpreted as aiming to increase understanding through explaining. Section develops a few examples illustrating the Aim of engagement of Substantiating Explanation. This contribution was therefore considered to be attempting to explain, that is, make understandable, that humans came from monkeys because of the similarity between human and monkey body structures. It's aim of engagement was therefore coded as, "Design Explanation". The following paragraph provides several examples of student contributions containing cues that were interpreted as indicating the student's aim was that of substantiation. In conclusion, due to the lack of indicators in the contribution, "*i think…humans were made of monkeys because of there body structure*", its aim of engagement was coded as "Design Explanation".

After the problem space (Domain) and the general epistemic aim within that space were coded, the next level of code attended to was the Stance Taken in the problem-solving cycle. Leveraging the Knowledge Improvement Cycle (KIC) there were two possible stances one can take when making a move in problem-solving: Solving and Testing. This contribution "*i think…humans were made of monkeys because of there body structure*", was coded as, "Solving" because it was a declarative statement which sought to move the question forward. The Level 4 code identified the knowledge type provided, that is the type of move made by the contribution. It was coded as a, "My Explanation" because no source outside of the student's own thinking was provided. Moreover, the sentence did not cite a source which in this research was considered necessary to be coded as a, "Source-based Explanation". Just as was done in this section, the title of the following sections provided the full, four- level code as the heading. Each section contains one or more student contributions. Brief explanation is given to an aspect of the coding.

4.4.1.2 Code: Advance Theory/Design Explanation/Solving/Source-based Explanation

The following student contribution is an example of another contribution that was posted at the root level of the Knowledge Building dialogue in Big Q1.

> *"humans and chimpanzees share a common ancestor but they don't come from each other i got my research from http://www.pbs.org/wgbh/nova/evolution/our-family-tree.html"*

This contribution shared the first three levels of codes with the first quote. It was considered to be working in the domain of advancing theory because it provided a description of ancestral relationship between distinct species, aiding the understanding of a phenomenon in the natural world. This contribution was coded as aiming to design. This was considered reasonable because there is no explicit indication that the agent is seeking to affiliate with a knowledge object nor seeking to influence colleagues' affiliation towards it. Nor was there an indication that the information provided by the agent was considered a claim instead of a fact and therefore not working in the domain of argumentation but instead was aiming at understanding. It was considered to be advanced from a, "Solving" stance as it was a declarative statement. Finally, it was coded as being a, "Source-based Explanation" as it provided a source considered reliable which was able to be accessed by an interested colleague.

4.4.1.3 Code: Advance Theory/Design Explanation/Solving/Summary

The following quote was also coded as working in the domain of "Advancing Theory" because it articulated a process that explained why the next generation is better adapted to the environment than the previous.

> *"Indeed, and that's why generations differ because the offspring are only from those who survived to reproduce. Those who have offspring are those most adapted to the environment of that particular population so far."*

It was coded as aiming to design an explanation. There was no explicit indication of seeking to substantiate or build community around the way of knowing and it did provide understanding. Furthermore, as the fourth contribution in a thread, the tone of the thread

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was seeking to provide understanding of a phenomenon, not engage with whether the explanation was correct or not, i.e., not seeking to engage in argumentation. The three contributions in the thread before it were:

1) The first comment:
"I think that the animals in the golopogose adapted to the new enviorment there. so in order to survive the had to change in the way that they had to be different then other species. those animals that there adaptiondident help them survive either died or moved to a different place"

2) The second comment:
"SO you are saying that the animals differ because of survival of the fittest?"

3) The third comment:
"yes that is exactly what I am saying. some animals couldent survive so they got iliminated"

It was coded as having been made from a solving stance, providing a Summary knowledge type. While from the writing there was nothing to distinguish it from a "My Explanation", the student had selected the Summary KT when posting and further it had a concluding role in that thread, coding it as a Summary KT was reasonable.

4.4.1.4 Advance Theory/Design Explanation/Testing/Problem

The next two contributions shown are coded as coming from a "Testing" stance. The following quote was coded as advancing theory:

"I don't remember this, perhaps I missed that lesson…."

It was considered to be advancing theory because it was posted to the following contribution which is working in a theoretical domain:

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"Like one week ago we were looking a video called the tree of live that said that we human develop from fish because they have something in their head that we have and is our ear."

The first contribution above (about not remembering) was coded as expressing a designing aim. This is reasonable as it was replying to a post that was coded as aiming for understanding. Furthermore, there was no indication of an effort at influencing idea affiliation, nor any effort to influence the belief-worthiness of an idea. As mentioned above, the contribution was seen to be from a Testing stance because it was not taking a declarative stance towards the science topic mentioned in the previous post. It was coded as a "Problem": it was not an interrogative but instead a description of a hypothetical reason for being unaware of the content of the previous post.

4.4.1.5 Advance Theory/Design Explanation/Testing/Question

Coding the second contribution from the testing stance given below was not straightforward:

talk more about how they migrated?

It was in the domain of advancing theory because and unknown phenomenon was the target. It was considered to be neither about building community nor substantiation as there were no explicit indicators of either and was therefore considered to have an aim of designing an explanation. Even though it was a declarative construction, its aim was seeking knowledge and was there for considered to be from a "Testing" stance. While this contribution did not begin with a common interrogative of who, what, where, when, why and how but instead had the structure of an imperative. Nonetheless, it sought

specific information on the process of how the animals migrated and was therefore considered a question.

As the coding pattern repeats substantially throughout the coding framework, this level of detail will not be used but instead a few quotes will be used to illustrate the distinct areas of the framework.

4.4.2 Code: Advance Theory/Substantiate Explanation/

The second aim of engagement in the advance theory domain was "Substantiating Explanation"

4.4.2.1 Code: Advance Theory/Substantiate Explanation/Solving/My Argument…

In this first example 2 contributions are shown, the first asks a question which is argued to be in design mode, and it is followed with a contribution that is argued to be in belief mode. A student asks,

> *"How could have apes had evolved into humans?"*

This question was considered to be aiming towards understanding and therefore its aim of engagement was coded as "design explanation". That was followed by this contribution:

> *"I don't think that they did, that's a common misunderstanding of evolution or so I hear. Try thinking of it more like humans and apes had a common ancestor, of course what you believe is up to you."*

There are a few indicators that this latter contribution was attempting to influence the belief worthiness of the previous student's assumption that apes evolved into humans. By starting the contribution with an assertion that the previous poster's idea is incorrect indicates an engagement in belief mode. That phrase was furthermore modified with, "I

don't think…", softening the assertion. It is possible that this softening of one's declarative statements is indicative that the agent's concern was about the correctness and not meaning. The next utterance, "…that's a common misunderstanding of evolution or so I hear." labels the previous student's assumption as a misunderstanding, i.e., that it is incorrect, and again added a softening modifier "… or so I hear." The next part of the utterance, "Try thinking of it more like humans and apes had a common ancestor, of course what you believe is up to you." In the first clause of this sentence there was no clear indicator that the student was aiming towards influencing the belief worthiness of an idea. However, the last part of that sentence, "… Of course *what you believe* is up to you." again indicated a focus on the belief worthiness of an idea, and again was delivered in a form that was aimed to soften the force of the assertion. Therefore, considering the various indicators that influencing belief-worthiness was the aim, this contribution was coded as substantiating an explanation.

The following contribution presents another way a student can work towards the epistemic aim of substantiation. This contribution was not posted as a reply to another student's contribution but as a root level post to the big question. The contribution says:

> *"What KInd Of Evidence Do Scientist Have About Humans Coming From Animals?... I THink That We Are Created By God".*

A defining feature of this contribution is its use of capitalization. This capitalization gives a strong sense of emphasis to its assertion, aiming to increase the credibility of the claim. This is an indicator that the student was attempting to influence the belief worthiness of the idea presented. This sense of forcefulness continues as the last sentence demands

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evidence to support the position opposite to the agents. Returning to the first sentence in the contribution, the phrase, "*What kind of evidence do scientists have…*", performs Gee's "Connection Task" in such a way as to "other" scientists, thereby working to decrease "scientists" relevance and therefore authority in this situation (Gee, 2011, p. 19). For these reasons, the student's contribution was coded as aiming towards substantiation.

The following contribution that was inferred to be aiming at substantiation:

> *According to the scientists, biologists and paleontologists in the movie: What Darwin Never Knew, I was able to confirm that the animals on the Galapagos Island differ from other animals because of reproductive isolation. Animals can't simply wish for a mutation, mutations happen randomly. A source that can help you understand is the website: http://gcos.mpls.k12.mn.us:8383/gcos10/mr.-groos/resources/science-units/evolution-ss/natural-selection*

Elements of this contribution such as using the names of the types of scientists as well as naming the specific evolutionary process "reproductive isolation", evoke a sense of credibility. The word "confirm" also indicates that something was shown to be valid. Furthermore, a short explanation, that animals can't simply wish for mutation, that they happen randomly, is given is embedded in the contribution, providing further weight to the contribution.

4.4.3 Code: Advance Theory/Build Community Around an Explanation/Solving/My Affiliation

The following contribution was considered to engage with the aim of building community around an explanation:

> *"Even though My explnation was diffrent I agree more to your explnation on how Darwin's work got noticed"*

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The agent explicitly disaffiliated himself from his own explanation and asserted a shared belief with the other student's explanation, which was explicitly identified.

4.4.4 Code: Build Relevance/Substantiate Relevance/Solving/Source-based Value Argument

the following contribution was considered to be working in the domain of the relevance of scientific theory. The agent states having that the theory of evolution is important, furthermore using words such as "logically" and "accurately" which are some of the power words for credibility in scientific discourse, indeed in the dominant US discourse. While no details were given why the theory of evolution was important, the end of the given citation: "Why_is_the_theory_of_evolution_important_to_doctors" states that the theory was important to doctors. There was a level of implied value as that which is important to doctors in their work is important to us as patient sometimes needing care.

> *"in my research it shows that the theory of evolution is important becase it shows how we logically and accurately got to be the way we are. http://wiki.answers.com/Q/Why_is_the_theory_of_evolution_important_to_doctors"*

4.4.5 Code: Develop Ways-of-knowing/Design Method/Solving/Summary

The following contribution was considered to be working in the domain of developing ways of knowing, that is, methods.

> *We are all agree that Darwin became with his theory of evolution by comparing the fossils to existing animals and by studying them carefully, to know if they had something in common and if all of them are descended from the same species from early days.*

It summarized Darwin's method used to develop his theory of evolution. It stated both what was done, a comparison, and the careful stance taken to the study. Furthermore, a basic analytic technique of comparison was given and the type of knowledge that this method could provide. These are important aspects of methods

4.4.6 Code: Improve KB Process/Design Explanation/Testing/Problem

The quote given below was considered to be working in the area of improving the process of Knowledge Building:

> *Humans evolved from fish 'and' humans? Excuse me, but I am rather confused by this?*

This contribution identified a "Problem" in a colleague's contribution. The problem was not concerning theory nor relevance nor way of knowing but instead it was a problem of professional communication. The problem would be resolved through a rewrite fixing the confusing part of the sentence.

4.5 Conclusions of code development process

Through these explicated examples of the coding system several conclusions are given. While there was evidence, that is, student contributions, that illustrated most of the codes, all of the levels of the coding hierarchy were represented as well as most if not all categories in each level. Where there were no contributions in certain areas the theoretical methods were able to suggest them. In the coding process I felt reasonably confident identifying the Level 1 problem domains in which the Knowledge Building had been done. Furthermore, the epistemic Stance Taken, Level 3, was able to be determined

without too much uncertainty. Determining the specific knowledge type of the contribution required developing a series of rules, i.e. a codebook, to gain a sense of reliability in their coding. For example, for contribution to be identified as "Source based" it needed to provide a source that the agent meant as credible and that could be checked. It is suggested that as these three levels of the coding system were relatively easy to apply, helping students gain an awareness of them would be well within reach. This will be further discussed in chapter 5.

The level of the hierarchy which provided the most uncertainty in the coding process was Level 2, Aim of engagement. The rule was created that a contribution needed to have explicit indications of working towards the aim of substantiation or else that code would not be considered. Likewise, there needed to be an indication that the contribution was aiming towards influencing the development of a community around whatever specific knowledge object was the focus. If there was not explicit indication of these aims, the work was considered to be aiming at improving the design of the knowledge object, that is, design mode work. This difficulty is to be expected as the contributions were often brief and therefore provided limited "exposure" to the mode of the students' engagement. Nonetheless, there was a significant sense that I was able to distinguish between these modes in the coding of the student contributions. The interrater reliability testing described in the next section provided evidence of the replicability of this coding system. Pedagogical as well as software design recommendations based on the

experience of coding the contributions will be provided in chapter 5, as well as implications to theory.

4.6 Validation: Interrater reliability testing

The coding system was applied to the comments in the following manner. First, the comment was read and based on its content, the comment was coded as occurring within one of the four domains. Next, based on its domain, it was coded as to its aim, there being three parallel aims for each domain. Next the stance taken towards that aim, either that of solving or testing, was chosen and finally, the tool used was assigned. The coding indicators that were used to code the contributions are provided in Appendix B and some detail as to how they were developed is described below in section 4.6.1.

4.6.1 Coding Indicators

The development of the framework occurred parallel to that of the coding system as they are essentially the same structures. During the development of the coding system notes were kept and updated with definitions of the different levels and codes. This document was useful in coding comments that were difficult to distinguish. It also provided a space to record insights into the nature of a particular category provided by an empirical instance of that category. Also, it provided a space to write down new categories suggested by the data.

4.6.2 Interrater reliability

When I completed the development of the coding system as indicated by being able to successfully apply the system to the entire data set with a good fit, I invited Dr.

Selcen Guzey to help with inter-rater reliability testing and she accepted. Dr. Guzey had been involved in this research indirectly since before the data was collect, providing occasional feedback over the years on all aspects of the research. To perform the inter-rater reliability check we sat down for approximately an hour session where I first introduced her to the final version of the coding system, both providing details and responding to her questions. She took notes on the diagrams I provided for her that were similar to Figure 10 but with more detail. Next, we coded the comments to central question 1 together. Through a process of gradual release of responsibility, she took greater responsibility assigning the codes to the comments. Her assignment of code was fairly consistently with mine by the time she got to the end of central question 1 and therefore we felt she was ready to perform the validation. Starting with the first comment in central question 2, she coded the first 20 comments. After she was done, I compared her code-assignments with mine and if there were any inconsistency in assignment for a comment that was considered a different coding. Of the 21 comments coded, 18 were in complete agreement providing an 86% agreement. We stopped after 21 comments as it felt that was sufficient. Based on this complexity of the coding—there are 4 levels of code to assign each comment, we felt this was fairly good agreement.

5 Conclusions, Implications and Suggestions for Further Research

"The problem is never "solved" in the traditional sense, you simply run out of resources" Jeff Conklin, 2003

"In other words, philosophical progress occurs whenever we transform an incongruous or inadequate conception so that it is now congruous and adequate and the original problem no longer occurs. This is progress, even though we have not reached a final settled position free from defensible competitors or from further problems and improvements" Clinton Golding, 2011

This study aimed to make Knowledge Building (KB) more understandable to students, teachers and researchers. This was done through three interrelated inquiries, the first two were based on literature alone and the third used an adapted version of qualitative template analysis that equally integrated philosophical and empirical methods. The major findings of this inquiry were informed by various areas of literature including ideas related to the philosophy of science. Especially important were the ideas that scientific inquiry is a type of problem-solving, Hintikka's interrogative model of inquiry, Popper's idea of world three and his tetradic iterative problem-solving model along with Hanson and Kuhn's conception of science involving not only theory improvement but theory transformation. Also important were research areas connected to design including Bereiter and Scardamalia's ideas of design and belief mode, Perkins conception of knowledge as design, researchers who developed ideas of design thinking as well as Edwards connection between the creative work done in drawing and identifiable cognitive modes or states. Finally, this research was also significantly informed by areas related to science education including the Knowledge Building and Progressive Inquiry

approaches as well as visions of inquiry advanced by the NSES and the opportunities and responsibilities provided by NGSS's acknowledgment the diversity in the students we teach. The key findings from this research included: the visual knowledge improvement cycle (KIC), considered as a type of problem-solving; the open-ended spawning of KIC's to represent emerging episodes of problem-solving chronicling the unfolding inquiry as a knowledge improvement map (KIM). The final product of this research was a tentative descriptive theory of KB from a problem-solving perspective.

5.1 Conclusions: the KIC and the KIM

The problems which elicited research questions one and two occurred in the many moments when the students and I needed a way to talk and think about knowledge improvement at a comprehensive yet simple level. The problem was revealed in our individual and shared efforts to describe, analyze, reflect and engage in Knowledge Building. The theoretical background and the resolutions to these two research questions were developed in chapter 2. Both research questions, RQ1:

> *"How can the process of knowledge improvement in science from a problem-solving perspective be succinctly described?",*

and RQ2:

> *How can a class' actual, unfolding, progressive-inquiry dialogue be mapped?"*

sought explanations. It was expected that the explanations would both provide a sense of understanding of the process of knowledge improvement as well as reflective utility to students and teachers in their respective roles in a knowledge building classroom. The

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answers that were developed to these questions can be considered to be models, they both

include the same five basic epistemic elements and their interrelationship in knowledge

problem-solving inquiry. Both models avail the affordances of two-dimensional space to

represent the nonlinear relationships of problem-solving and inquiry in a graspable

manner.

5.1.1 The knowledge improvement cycle (KIC)

The answer to RQ1, the KIC, integrated ideas from Popper's tetradic model

representing problem-solving, Popper's world-three (W3) idea that a community creates

and works on shared knowledge objects in this abstract world of cultural artifacts, and

Hintikka's interrogative model of inquiry asserting that we come to understand the natural

world through a process of interrogating nature in a goal-directed, back and forth

question - answer process. The KIC represents the relationships between the elements in

a single problem-solving episode. The essential elements defined in a problem-solving

episode include: the central problem, the solving activity, the testing activity, and the

knowledge object created through these opposing yet complementary activities: a

tentative solution and a new problem. This visual model presented earlier is represented

again below in
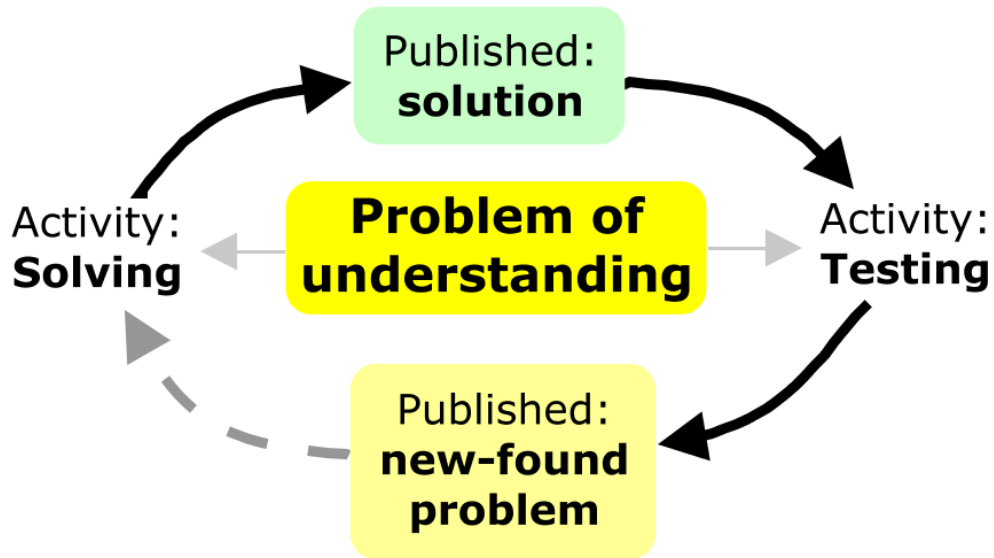
Figure 5.1: Five element knowledge improvement cycle (KIC).

The aim of this model is to make the cyclical process of knowledge improvement more understandable. Four unique aspects of this five-element model afforded understanding of knowledge improvement: 1) the KIC included only two activities the two described by the interrogative model of inquiry to be essential. This feature provided simplicity and epistemic focus. It was therefore both precise and descriptive, yet open and flexible. Additional flexibility is afforded by the arrows exiting the central problem space, showing that one can exit the problem space to solving the problem or to testing it. 2) By assigning the developed KO as its own element in the knowledge improvement cycle, this feature provided clear ontological separation from the preceding element, the activity which produced it. This clear boundary between successive elements in the cycle creates a sense of simplicity as well, the stages in the cycle do not blend in to each other and therefore can occupy our working mind on their own however, they are always present and available to provide context for each other when the epistemic need arises. 3)

the KIC provided an explicit and central location for the problem or question around which the activity is centered, analogous to its role in problem-solving. 4) This problem-solving model is fairly generic in application, adaptable to different types of problems and different problem-solving aims within those problem spaces.

Limitations of this model include the fact that it is only useful to describe problem-solving where some material or virtual object embodying the created KO was developed. That is, the KIC is not to effective at representing an individual's cognition or the distributed cognition occurring in a group's lively verbal discussion. These problem-solving efforts may be considered as abductive problem-solving, where the solution or new problem is an irreducible emergent of the solving and testing activities. Furthermore, when problem-solving involves more than a single problem-solving cycle the KIC has no affordance to present further iterations of problem solving. This limitation was addressed by RQ2.

5.1.2 The knowledge improvement map (KIM)

The second model developed in response to RQ2. This model is a method to represent an open ended, progressive knowledge improvement discourse. As the KIC ably represented a single problem-solving cycle, with the proper representational logic guiding the structure of the emergence of further problem-solving episodes, a map representing an unfolding inquiry is displayed, known as the KIM. The aim of the KIM was to make the problem-solving episodes in an extended and complex inquiry more understandable, that is easier to grasp.

Unique aspects of the knowledge improvement map included the ability to represent unlimited problem-solving episodes. Typically, visual models attempting to represent iterations of a cycle use representational logic such that the cycle expands in a 2-dimensional spiral or 3-dimensional helix. These approaches are inadequate to represent extended inquiry. By adopting a modular approach to representing iterations of a cycle, possible permutations in the unfolding of an inquiry can be represented including branching, where, for example, several important problems are discovered while testing a single solution as represented in Figure 5.2. In a similar manner, the KIM is able to represent several problems emerge from a single *problem*. Dead ends in an inquiry are common and are evident in the KIM by when a KIC has no further knowledge improvement cycles emerging from it. KIM furthermore retains the flexibility of the KIC: while a general directionality is implied by the KIC, it nonetheless equally represents any sequence of problem-solving activities. The modular approach of the KIM incorporating the similar visual configuration of multiple KIC's serve as a visual heuristic, reducing the complexity of the emerging inquiry. This supports grasping the emerging state of the communities inquiry allowing for more effective engagement with the inquiry. Finally, different sets of rules governing the structure of the emergence of one episode from its previous are possible. For example, note the difference between Figure 5.2 and Figure 2.11, each knowledge improvement map uses different rules defining the emergence and representation of the KIC's.

A limitation of this model stems from the fact that different sets of rules governing the structural emergence of the KIM have not yet received much development effort and so the model is not highly refined. While features of the KIM serve to reduce the cognitive load required to understand extended inquiry, nonetheless, the rules governing the emerging structure of problem-solving episodes require effort and time to gain a level of automaticity in interpreting them.

Figure 5.2 Example showing flexibility of representational approach

In conclusion, The KIC and the KIM can be used in a variety of problem-solving context in different ways, corresponding to roles and epistemic aims of the agents in a Knowledge Building community. Taken together, these two models support both students and teachers to more effectively engage in their role in a Knowledge Building community by making the process of knowledge building more graspable. The following examples illustrate uses of the knowledge improvement cycle KIC and the knowledge improvement map KIM from the different agents' perspectives.

5.2 Conclusions: the descriptive theory

Research question 3 sought to integrate diverse theories considered promising to understand Knowledge Building into an empirically valid framework:

> *What is a descriptive theory of Knowledge Building in the science class in terms of: types of problems, epistemic and social moves that take into account the ideas of design and belief mode and the need to develop consensus around developing theories, and problem-solving using specific types of knowledge objects?"*

The final product, referred to as a "descriptive theory of knowledge building in science from a problem-solving perspective" will be referred as the descriptive theory or framework or coding framework or hierarchy. RQ3 called for a descriptive theory as little was known of a problem-solving view of knowledge building that integrated the ideas of problem solving, design and belief mode and the idea of knowledge building as "dialogic moves" towards epistemic and social aims. A descriptive theory labels the conceptual structure of an area: the concepts and relationships between them. In this case the classificational structure was a taxonomy.

Due to the methods used to answer RQ3, the descriptive theory and the coding system were the same structure. Hybrid philosophical - empirical methods were required to address the needs of research question three. RQ3 asked a normative question, it did not seek to know what knowledge building was in the six week Evolution unit, but what knowledge building ideally could be. Nonetheless, empirical methods were required to ensure that the developing theory was also faithful to the knowledge building dialogue enacted by the students. Qualitative template analysis was adapted to embed the philosophical methods alongside its empirical methods. This process could be considered an iterative problem-solving approach: The philosophical methods permitted diverse theory to inform the transformations of a coding system and the empirical methods served to test and develop this coding system and to maintain fidelity with actual student dialogue.

The descriptive framework was generally consistent with the theoretical areas described above however, there are several unique aspects of this descriptive framework the framework can be said to describe an instance of a dialogical move, that is a student contribution, when engaged in KB dialogue. That is to say, it was able to describe all student contributions in a knowledge building discussion. Before describing the utility and possibilities of this framework it is important to note that the biggest limitation of descriptive theories in general is the converse of their greatest strength. Through creating a theoretical space for the phenomenon by declaring the relevant concepts and drawing out their interrelationships, it of necessity omits other concepts and relationships that can

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also describe the phenomenon but from a different theoretical perspective. In this sense the development of a descriptive theory is sensitive to the biases of the individuals and communities which it represents, an important consideration when working with a descriptive theory.

5.2.1 The descriptive theory

Using the descriptive framework, a dialogical move can be described by four interrelated concepts corresponding to the four levels of the taxonomy. The most encompassing level, Level 1 as shown again in **Error! Reference source not found.**, names the overarching problem space in which an agent might work to solve. There were considered to be four distinct problem spaces in science: solving theoretical problems, problems related to the relevance of these developing theories, problems relating to appropriate methods of creating knowledge in the specific field, and finally process problems such as communication which was emphasized in this research, but also problems between members and possibly operational processes, that is, problems of running the organization.

Next, at Level 2 of the hierarchy within each Level 1 problem space there can be considered to be three broad aims of engagement: one that considered to be essentially creative, i.e., the design mode aim, another considered the analytic, belief mode aim, and the last describing the social/political aim evoked when working to develop community around the KO's developed through knowledge work. It is important to understand that an agent engaged in a particular problem space with a particular epistemic aim is not expected to necessarily continue in that problem space or with that aim. Agents easily

switch between problem spaces and aims within the spaces as called for epistemic goals emerge in their unfolding inquiry.

Next, as shown on Level 3 of the hierarchy, one can take one of two stances within towards one's aim: solving or testing, corresponding to the two main activities in the KIC.

Finally depending on which of the two stances are taken a specific set of moves are available. In this research the moves identified were based on the progressive inquiry set of knowledge types provided with FLE4. The three solving knowledge types included: providing intuitive knowledge, source-based knowledge or a summary of knowledge in the KB dialogue. The two testing knowledge types included advancing a problem, or advancing a question. In conclusion a student's contribution was considered to be able to be described by four characteristics: the type of problem space in which it worked, its aim within that problem space, it's problem-solving stance towards that aim and the specific type of knowledge being provided or sought. The following presents implications and suggestions for future research.

5.3 Implications and suggestions for future research

KIC helps to scaffold both students' independent engagement in online Knowledge Building dialogue, engaging in their small groups and in private reflection on their own work that day. The KIC can scaffold students as they describe, analyze and reflect on KB as it represents the elements of their knowledge improvement and describes possible relationships between those elements. As a teacher, a concurrent use of KIM is

to scaffold student understanding of the structure of ongoing, iterative knowledge improvement dialogue. After students have been introduced to the KIC and are familiar with using it to represent single iterations of problem-solving, but before they have engaged in KB dialogue online, students are shown a three-minute instructional video that I have produced based on the KIM. This video presents an actual KB dialogue that unfolded in a class a previous year. This previous KB dialogue is represented through KIM by placing student contributions in their corresponding places on the unfolding KIC's. Thought-bubbles are used to represent the activity elements of the KIC. As the video proceeds, the KIM visualization of the dialogue unfolds according to the dialogue that had happened in that class.

Knowledge building is a complex, abstract process, requiring substantial time and effort for many students to grasp it. These models provided teachers with additional concepts when teaching students and helping them understand Knowledge Building, allowing for subtle yet constant integration of knowledge building throughout all types of classroom activities. For example, to introduce an activity where an important aim is for students to discover problems and questions I, in this example, point to the center problem space of the knowledge improvement cycle on the KIC poster on the wall as I mention the aim of discovering problems. When telling students that they will be writing down any problems and questions they discover on the yellow piece of paper I'm holding up, I point to the problem/question KO element at the bottom of the KIC which is also yellow in the color diagram. To scaffold student analysis during a whole class discussion

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of an ongoing Knowledge Building discussion represented on the Promethean board at front, as I'm saying, "Identify contributions that are *solutions* to one of the core problems in your KB work" or, "What is one way *this solution* helps us understand the phenomenon?" I point to the "Solution KO" location on the KIC. In conclusion, these models provide additional terms and further tools, embedded in a meaningful model that is visually represented, and thereby increases the conceptual "surface area" of Knowledge Building, thereby providing increased access points for the students.

These models provide possible heuristics for the development of new or improved Knowledge Building environments. For example, the KIC could be used as a visual element in Knowledge Building software cueing, that is channeling, student participation through effective epistemic moves. Furthermore, the KIC diagram could be part of a larger representational system such that, as students respond to each other, the contributions get represented as a KIM. Furthermore, just as the knowledge types, scaffold student epistemic moves, the different levels defined by the descriptive theory could be embedded to provide different levels of scripting support, taking into account concerns of over and under scripting.

An essential aspect of learning is reflection on one's own performances. Different performance metrics based on the elements and structures within the descriptive theory could be quantified through natural language processing data analytics. These measurements could be availed by the student in a personal dashboard where they could come to understand their strengths and weaknesses in building knowledge and in the

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process internalize and understand the complex aspects of knowledge building. The KIM representation would likewise present affordances for developing personal dashboards to represent one's engagement in the class' Knowledge Building. Furthermore, the KIM representation affords understandable representations of the state of the knowledge building dialogue at any one time. This state-representation capability of the KIM would provide a useful platform for developing portfolios to reflect on and document one's progress as a sophisticated knowledge builder. Software structured by these three products presents correspondingly important opportunities to teachers and researchers.

There are important lines of research resulting from the use of these products in class by students and teachers. For example, a challenge in instantiating a Knowledge Building community is the heavy dependence on the teacher to help students analyze and reflect on their own and the class' discourse. It would be helpful to know in what ways the use of the model helps students gain independence in this analysis and reflection. Another area of research interest includes finding out how the use of these models, but especially the KIC, relates to students' confidence affective responses with Knowledge Building activities. An additional research area would be to describe the ways that these models aid students in gaining a deeper understanding of the nature of science.
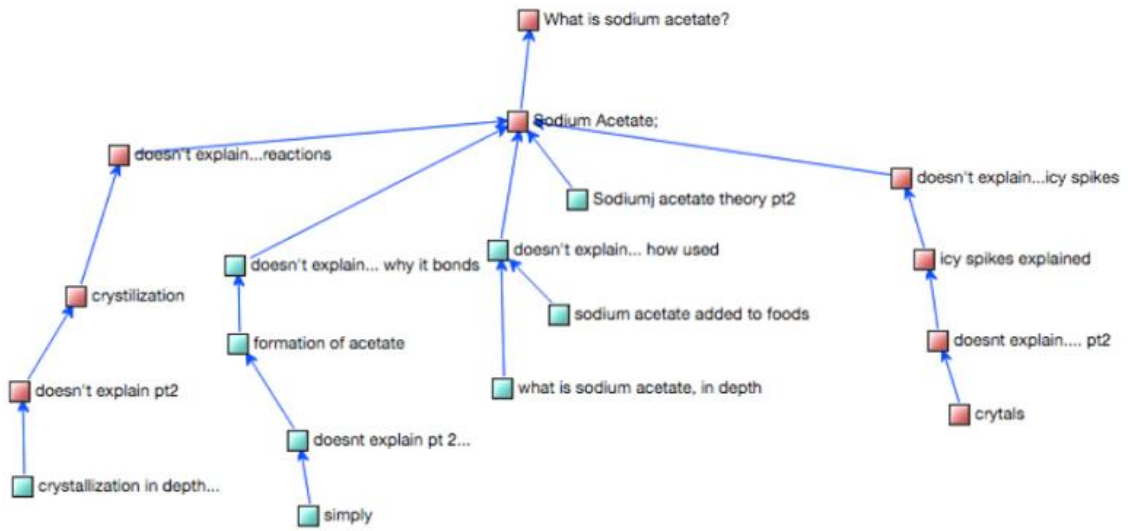
Figure 5.3 A screenshot from Knowledge Forum 6, use by the author's classes since 2015.

Bibliography

Arnseth, H., & Säljö, R. (2007). Making sense of epistemic categories. Analysing students' use of categories of progressive inquiry in computer mediated collaborative activities. *Journal of Computer Assisted Learning*, *23*(5), 425–439. https://doi.org/10.1111/j.1365-2729.2007.00225.x

Bereiter, C. (1992). Referent-centred and problem-centred knowledge: Elements of an educational epistemology. *Interchange*, *23*(4), 337–361. https://doi.org/10.1007/BF01447280

Bereiter, C. (2002). *Education and mind in the knowledge age*. Mahwah, N.J: Routledge.

Bereiter, C., & Scardamalia, M. (1996). Rethinking learning. In D. R. Olson & N. Torrance, *The handbook of education and human development: New models of learning, teaching, and schooling* (pp. 485–513). Cambridge, Mass.: Blackwell Publishers.

Bereiter, C., & Scardamalia, M. (2003). Learning to work creatively with knowledge. *Powerful Learning Environments: Unravelling Basic Components and Dimensions*, 55–68.

Bereiter, C., & Scardamalia, M. (2006). Education for the knowledge age: Design-centered models of teaching and instruction. In *Handbook of educational psychology* (pp. 695–713). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Bereiter, C., & Scardamalia, M. (2014). *Knowledge building and knowledge creation: One concept, two hills to climb*. 35–52. https://doi.org/10.1007/978-981-287-047-6_3

Bereiter, C., & Scardamalia, M. (2016). "Good Moves" in knowledge-creating dialogue. *QWERTY - Interdisciplinary Journal of Technology, Culture and Education*, *11*(2), 12–26.

Bird, A. (2018). Thomas Kuhn. In E. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Winter 2018). Retrieved from https://plato.stanford.edu/archives/win2018/entrieshomas-kuhn/

Boland, R., & Collopy, F. (2004). *Managing as designing*. Stanford, CA: Stanford Business Books.

Boyd, B. (2016). Popper's world 3: Origins, progress, and import. *Philosophy of the Social Sciences*, *46*(3), 221–241. https://doi.org/10.1177/0048393116640282

Braun, V., Clarke, V., Hayfield, N., & Terry, G. (2018). Thematic analysis. In P. Liamputtong (Ed.), *Handbook of Research Methods in Health Social Sciences* (pp. 1–18). https://doi.org/10.1007/978-981-10-2779-6_103-1

Brown, J., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Bruner, J. (1996). *The culture of education*. Cambridge, MA: Harvard University Press.

Burton, S., & Dobson, C. (2009). Spork & beans: Addressing evolutionary misconceptions. *American Biology Teacher*, *71*(2), 89–91.

Bybee, R. (2011). Inquiry is essential. *Science & Children*, *48*(7), 8.

Charmaz, K. (2008). Grounded theory as an emergent method. In S. Hesse-Biber & P. Leavy (Eds.), *Handbook of Emergent Methods* (pp. 155–172). New York, NY: The Guilford Press.

Chen, B., & Hong, H.-Y. (2016). Schools as knowledge-building organizations: Thirty years of design research. *Educational Psychologist*, *51*(2), 266–288. https://doi.org/10.1080/00461520.2016.1175306

Cohen, D. (1995). Argument is war... And war is hell: Philosophy, education, and metaphors for argumentation. *Informal Logic*, *17*(2). Retrieved from http://phaenex.uwindsor.ca/ojs/leddy/index.php/informal_logic/article/view/2406

Conklin, J. (2005). *Dialogue mapping: Building shared understanding of wicked problems*. Chichester, England; Hoboken, NJ: John Wiley & Sons, Inc.

Conklin, J. (2008). *Wicked problems and social complexity*. Retrieved from https://cognexus.org/wpf/wickedproblems.pdf

Dabbagh, N., & Bannan-Ritland, B. (2005). *Online learning: Concepts, strategies, and application*. Upper Saddle River, NJ: Pearson/Merrill/Prentice Hall.

Demerath, L., & Suarez, D. (2019). Teaching complexity as transdisciplinarity. In T. Carmichael, A. Collins, & M. Hadžikadić (Eds.), *Complex adaptive systems: Views from the physical, natural, and social sciences* (pp. 223–250). https://doi.org/10.1007/978-3-030-20309-2_11

Dewey, J. (1938). *Logic: The theory of inquiry*. New York, NY: Henry Holt.

Dobzhansky, T. (2013). Nothing in biology makes sense except in the light of evolution. *The American Biology Teacher*, *75*(2), 87–91. https://doi.org/10.2307/4444260

Donald, M. (1991). *Origins of the modern mind: Three stages in the evolution of culture and cognition*. Harvard University Press.

Dorst, K. (2006). Design problems and design paradoxes. *Design Issues*, *22*(3), 4–17.

Edwards, B. (1979). *Drawing on the right side of the brain: A course in enhancing creativity and artistic confidence*. Los Angeles, CA ; New York, NY: JPTarcher ; Distributed by StMartin's Press.

Edwards, B. (1989). *Drawing on the right side of the brain: A course in enhancing creativity and artistic confidence* (Rev. ed..). Los Angeles, CA ; New York, NY: JPTarcher ; Distributed by StMartin's Press.

Fawcett, J., & Downs, F. (1986). *The relationship of theory and research*. Norwalk, CT: Appleton-Century-Crofts.

Fischer, F., Kollar, I., Stegmann, K., & Wecker, C. (2013). Toward a script theory of guidance in computer-supported collaborative learning. *Educational Psychologist*, *48*(1), 56–66. https://doi.org/10.1080/00461520.2012.748005

Gallard, A., Mensah, F., & Pitts, W. (2014). *Supporting the implementation of the Next Generation Science Standards (NGSS) through research: Equity*. Retrieved from https://www.narst.org/NGSSpapers/equity.cfm

Gee, J. (2011a). *An introduction to discourse analysis: Theory and method* (3rd ed). Milton Park, Abingdon ; New York, NY: Routledge.

Gee, J. (2011b). *How to do discourse analysis: A toolkit*. Milton Park, Abingdon; New York, NY: Routledge.

Golding, C. (2015). The community of inquiry: Blending philosophical and empirical research. *Studies in Philosophy and Education*, *34*(2), 205–216. https://doi.org/10.1007/s11217-014-9420-9

Guzzetti, B., Snyder, T., Glass, G., & Gamas, W. (1993). Promoting conceptual change in science: A comparative meta-analysis of instructional interventions from reading education and science education. *Reading Research Quarterly*, *28*(2), 117–159. https://doi.org/10.2307/747886

Hakkarainen, K. (1998). *Epistemology of scientific inquiry and computer-supported collaborative learning* (PhD Thesis). University of Toronto, Toronto, Canada.

Hakkarainen, K. (2003). Emergence of progressive-inquiry culture in computer-supported collaborative learning. *Learning Environments Research*, *6*(2), 199–220. https://doi.org/10.1023/A:1024995120180

Hakkarainen, K. (2009). A knowledge-practice perspective on technology-mediated learning. *International Journal of Computer-Supported Collaborative Learning*, *4*(2), 213–231. https://doi.org/10.1007/s11412-009-9064-x

Hakkarainen, K., & Sintonen, M. (2002). The interrogative model of inquiry and computer-supported collaborative learning. *Science & Education*, *11*(1), 25–43. https://doi.org/10.1023/A:1013076706416

Hanson, N. (1958). *Patterns of discovery: An inquiry into the conceptual foundations of science*. Cambridge MA; New York NY: Cambridge University Press.

Hewitt, J., & Scardamalia, M. (1998). Design Principles for Distributed Knowledge Building Processes. *Educational Psychology Review*, *10*(1), 75–96. https://doi.org/10.1023/A:1022810231840

Hintikka, J. (1981). On the logic of an interrogative model of scientific inquiry. *Synthese*, *47*(1), 69–83. https://doi.org/10.1007/BF01064266

Hofweber, T. (2018). Logic and Ontology. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Summer 2018). Retrieved from https://plato.stanford.edu/archives/sum2018/entries/logic-ontology/

Huang, P., Qiu, L., Shen, L., Zhang, Y., Song, Z., Qi, Z., … Xie, P. (2013). Evidence for a left-over-right inhibitory mechanism during figural creative thinking in healthy nonartists. *Human Brain Mapping*, *34*(10), 2724–2732. https://doi.org/10.1002/hbm.22093

Jonassen, D. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development*, *48*(4), 63–85.

King, N., & Brooks, J. (2017a). Doing template analysis: A guide to the main components and procedures. In *Template Analysis for Business and Management Students* (pp. 25–46). https://doi.org/10.4135/9781473983304

King, N., & Brooks, J. (2017b). *Template analysis for business and management students*. https://doi.org/10.4135/9781473983304

Koschmann, T. (2002). Dewey's contribution to the foundations of CSCL research. *Proceedings of the Conference on Computer Support for Collaborative Learning:*

Foundations for a CSCL Community, 17–22. International Society of the Learning Sciences.

Kuhn, D. (1999). A Developmental Model of Critical Thinking. *Educational Researcher*, *28*(2), 16–46. https://doi.org/10.3102/0013189X028002016

Kuhn, T. (1962). *The structure of scientific revolutions*. Chicago, IL: University of Chicago Press.

Kuhn, T. S. (1970). *The structure of scientific revolutions* (2nd ed.). Chicago, IL: University of Chicago Press.

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal*, *32*(3), 465–491. https://doi.org/10.2307/1163320

Lakatos, I., Worrall, J., & Zahar, E. (1976). *Proofs and refutations: The logic of mathematical discovery*. Cambridge University Press.

Latour, B. (1987). *Science in Action: How to Follow Scientists and Engineers Through Society*. Harvard University Press.

Latour, B., & Woolgar, S. (2013). *Laboratory life: The construction of scientific facts*. Princeton University Press.

Laudan, L. (1978). *Progress and Its Problems: Towards a Theory of Scientific Growth*. University of California Press.

Leinonen, T., & Durall, E. (2014). Design thinking and collaborative learning. *Comunicar*, *XXII*. https://doi.org/10.3916/C42-2014-10

Lipscomb, M. (2012). Abductive reasoning and qualitative research. *Nursing Philosophy*, *13*(4), 244–256. https://doi.org/10.1111/j.1466-769X.2011.00532.x

Lipton, P. (1991). *Inference to the Best Explanation* (y First printing edition). London, England; New York, NY: Routledge.

Mullins, P. (2002). Peirce's Abduction and Polanyi's Tacit Knowing. *The Journal of Speculative Philosophy*, *16*(3), 198–224.

Mutanen, A. (2015). Hintikka's Interrogative Model and a Logic of Discovery and Justification. *Acta Baltica Historiae et Philosophiae Scientiarum*, *3*, 27–44. https://doi.org/10.11590/abhps.2015.1.02

Muukkonen, H., Hakkarainen, K., & Lakkala, M. (1999). Collaborative Technology for Facilitating Progressive Inquiry: Future Learning Environment Tools. *Proceedings of the 1999 Conference on Computer Support for Collaborative Learning*. Presented at the Palo Alto, California. Retrieved from http://dl.acm.org/citation.cfm?id=1150240.1150291

Muukkonen, H., Hakkarainen, K., Lipponen, L., & Leinonen, T. (1999). *Computer support for knowledge building*. *Helsinki, Finland*.

National Research Council. (1996). *National Science Education Standards*. Washington, DC: National Academies Press.

National Research Council. (2000). *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*. https://doi.org/10.17226/9596

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. https://doi.org/10.17226/18290

Öhman, J., & Öhman, M. (2013). Participatory approach in practice: An analysis of student discussions about climate change. *Environmental Education Research*, *19*(3), 324–341. https://doi.org/10.1080/13504622.2012.695012

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching*, *40*(7), 692–720.

Osborne, J., & Patterson, A. (2011). Scientific argument and explanation: A necessary distinction? *Science Education*, *95*(4), 627–638.

Owen, C. (2007). Design thinking: Notes on its nature and use. *Design Research Quarterly*, *2*(1), 16–27.

Paavola, S. (2007). Abductive logic of discovery with distributed means. *Abduction and the Process of Scientific Discovery*, 47–62.

Paavola, S., & Hakkarainen, K. (2005). The knowledge creation metaphor – An emergent epistemological approach to learning. *Science & Education*, *14*(6). https://doi.org/10.1007/s11191-004-5157-0

Peirce, C. (1974). *Collected Papers of Charles Sanders Peirce*. Belknap Press of Harvard University Press.

Perkins, D. (1986). *Knowledge as design*. L. Erlbaum Associates.

PhET Interactive Simulations. (n.d.). Retrieved July 20, 2019, from PhET website: https://phet.colorado.edu/

Popper, K. (1959). *The Logic of Scientific Discovery*. Routledge.

Popper, K. (1972). *Objective knowledge: An evolutionary approach*. Oxford, England: Clarendon Press.

Reichertz, J. (2004). 4.3 Abduction, Deduction and Induction in Qualitative Research. In *A Companion to Qualitative Research* (pp. 159–164).

Reichertz, J. (2009). Abduction: The Logic of Discovery of Grounded Theory. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, *11*(1). https://doi.org/10.17169/fqs-11.1.1412

Ritella, G., & Hakkarainen, K. (2012). Instrumental genesis in technology-mediated learning: From double stimulation to expansive knowledge practices. *International Journal of Computer-Supported Collaborative Learning*, *7*(2), 239–258. https://doi.org/10.1007/s11412-012-9144-1

Rodriguez, A. (2015). What about a dimension of engagement, equity, and diversity practices? A critique of the next generation science standards. *Journal of Research in Science Teaching*, *52*(7), 1031–1051. https://doi.org/10.1002/tea.21232

Roehrig, G. H., Groos, D., & Guzey, S. S. (2014). Developing collective decision-making through future learning environments. In M. P. Mueller, D. J. Tippins, & A. J. Stewart (Eds.), *Assessing Schools for Generation R (Responsibility): A Guide for Legislation and School Policy in Science Education* (pp. 227–242). https://doi.org/10.1007/978-94-007-2748-9_16

Roehrig, G., Luft, J. A., & Edwards, M. (2001). Versatile vee maps. *Science Teacher*, *68*(1), 28–31.

Sandelowski, M., & Barroso, J. (2003). Classifying the Findings in Qualitative Studies. *Qualitative Health Research*, *13*(7), 905–923. https://doi.org/10.1177/1049732303253488

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal education in a knowledge society* (pp. 67–98). Chicago, IL: Open Court.

Scardamalia, M., & Bereiter, C. (1993). Computer support for knowledge-building communities. *The Journal of the Learning Sciences*, *3*(3), 265–283.

Scardamalia, M., & Bereiter, C. (2006a). FCL and knowledge building: A continuing dialogue. *Institute for Knowledge Innovation and Technology, University of Toronto*. Retrieved from http://ikit.org/fulltext/AnnBrownOct10.06.pdf

Scardamalia, M., & Bereiter, C. (2006b). Knowledge building: Theory, pedagogy, and technology. In R. K. Sawyer (Series Ed.), *Cambridge Handbooks in Psychology. Cambridge Handbook of the Learning Sciences* (pp. 97–118). Cambridge ; New York: Cambridge University Press.

Scardamalia, M., & Bereiter, C. (2007). Fostering communities of learners and knowledge building: An interrupted dialogue. *Children's Learning in the Laboratory and in the Classroom: Essays in Honor of Ann Brown*, 197–212.

Scardamalia, M., & Bereiter, C. (2010). A brief history of knowledge building. *Canadian Journal of Learning and Technology / La Revue Canadienne de l'apprentissage et de La Technologie*, *36*(1). https://doi.org/10.21432/T2859M

Schank, R. C. (1999). *Dynamic memory revisited*. Cambridge, England; New York, NY: Cambridge University Press.

Schön, D. (1983). *The reflective practitioner: How professionals think in action* (Vol. 5126). Basic books.

Schrage, M. (1995). *No more teams: Mastering the dynamics of creative collaboration*. New York, NY: Doubleday.

Simon, H. (1996). *The sciences of the artificial* (3. ed., [Nachdr.]). Cambridge, MA: MIT Press.

Sintonen, M. (1993). In search of explanations: From why-questions to Shakespearean questions. *Philosophica*, *51*(1), 55–81.

So, H.-J., Tan, E., & Tay, J. (2010, August). *Fostering collaborative knowledge building culture: Initial experiences in the context of mobile learning*. Retrieved from https://repository.nie.edu.sg//handle/10497/6260

Stahl, G. (2006). *Group Cognition: Computer Support for Building Collaborative Knowledge*. Retrieved from https://www.barnesandnoble.com/w/group-cognition-gerry-stahl/1103854492?ean=9780262195393

Stevens, B. (1984). *Nursing theory: Analysis, application, evaluation* (2nd ed.). Boston, MA: Little, Brown, and Company.

Suddaby, R. (2006). From the Editors: What Grounded Theory is Not. *Academy of Management Journal*, *49*(4), 633–642. https://doi.org/10.5465/amj.2006.22083020

Thornton, S. (2018). Karl Popper. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Fall 2018). Retrieved from https://plato.stanford.edu/archives/fall2018/entries/popper/

Toikkanen, T. (2008). *Detailed diagram of the Progressive Inquiry model*. Unpublished manuscript, Media Lab, School of Art and Design, Aalto University, Helsinki, Finland.

Vaismoradi, M., Turunen, H., & Bondas, T. (2013). Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nursing & Health Sciences*, *15*(3), 398–405. https://doi.org/10.1111/nhs.12048

Vygotsky, L. (1978). *Mind and society: The development of higher mental processes*. Cambridge, MA: Harvard University Press.

Wagemans, J., Feldman, J., Gepshtein, S., Kimchi, R., Pomerantz, J., van der Helm, P., & van Leeuwen, C. (2012). A century of Gestalt psychology in visual perception: II. Conceptual and theoretical foundations. *Psychological Bulletin*, *138*(6), 1218–1252. https://doi.org/10.1037/a0029334

Walton, D. (1998). *The new dialectic: Conversational contexts of argument*. Buffalo, Toronto: University of Toronto Press.

What Darwin Never Knew—NOVA / PBS. (n.d.). Retrieved from http://www.pbs.org/wgbh/nova/evolution/darwin-never-knew.html

Appendix A

Code indicators:

Domain-- **Advance Theory**: When the comment seeks to solve a problem of understanding, that is, develop an explanation.

Aim-- **Design Explanation**: When the aim is to increase understanding of a phenomenon

Stance-- **Solving**: when the aim is to provide ideas, facts, explanations, clarifications etc.

Tool-- **My Explanation**: when the aim is to solve using 'local' knowledge--no outside source is referred to.

Tool-- **Source-based explanation**: when the aim is to solve using 'outside' knowledge. The outside source is expected to be reliable and able to be checked.

Tool-- **Summary**: when the aim is to summarize thread or threads within a discussion—indicated only if student selects this knowledge type.

Stance-- **Testing**: when the aim is to problematize or query any solution or test. This activity produces a "test".

Tool-- **Question**: when the aim is to interrogate any solution or test.

Tool-- **Problem**: when the aim is to 'point to', i.e., describe a problem with a solution or test.

Aim-- **Substantiate position**: When the aim is to engage with the belief-worthiness of a claim

Stance-- **Solving**: when the aim is to substantiate a position on an explanation, i.e., a position on its validity

Tool-- **My Claim**: when the aim is to advance a claim, or advance evidence or reasoning to support a claim, using 'local' knowledge--no outside source is referred to

Tool-- **Source-based explanation**: when the aim is to advance a claim, or advance evidence or reasoning to support a claim using 'outside' knowledge. The source must be made explicit and is expected to be reliable and able to be checked.

Tool-- **Summary**: when the aim is to summarize a thread or threads within a discussion--chosen if student selects that knowledge type

Stance-- **Testing**: when the aim is to question or problematize the belief-worthiness of an explanation/claim

    Tool-- **Question**: when the aim is to interrogate an explanation/claim, summary, problem or question

    Tool-- **Problem**: when the aim is to 'point to', i.e., describe a problem with an explanation/claim, summary, problem or question

Aim-- **Build community around explanation**: When the aim is to influence connections people and communities to explanations

    Stance-- **Solving**: when the aim is to establish a connection to another person's explanation--explicitly referring to the person

        Tool-- **My Affiliation**: when the aim is to connect/disconnect to another person + idea. (often, "I agree with...", "I disagree with...")

        Tool-- **Community-based Affiliation**: when the aim is to connect an external community to a person + idea.

        Tool-- **Summary**: when the aim is to summarize connections (around an explanation) within a community

    Stance-- **Testing**: when the aim is to test a connection or group of connections around an explanation.

        Tool-- **Question**: when the aim is to interrogate a connection(s) within a community around an explanation/claim.

        Tool-- **Problem**: when the aim is to 'point to', i.e., describe a problem with a connection or group of connections around an explanation, or a related problem or question

Domain-- **Build Relevance**-- When the comment seeks to solve a problem related to the value or importance of any idea or question.

    Aim-- **Design relevance**: When the aim is to increase the value, i.e., sense of worth of an explanation

        Stance-- **Solving**: when the aim is to advance the design of the relevance of an explanation.

            Tool-- **My Value-Statement**: when the aim is to advance the relevance with personal knowledge only.

            Tool-- **Source-based Value-Statement**: when the aim is to advance the relevance using knowledge external from oneself. The source must be made explicit and is expected to be reliable and able to be checked.

Tool-- **Summary**: when the aim is to summarize previous comments about the design of the relevance.

Stance-- **Testing**: when the aim is to test a value statement so as to understand it or improve its design.

Tool-- **Question**: when the aim is to interrogate a value statement or its test.

Tool-- **Problem**: when the aim is to problematize a value statement or its test.

Aim-- **Substantiate relevance**: When the aim is to argue the validity of a claim of relevance.

Stance-- **Solving**: when the aim is to increase the validity of a relevance claim.

Tool-- **My Relevance Claim**: when the aim is to advance the validity of a relevance claim based on personal knowledge only.

Tool-- **Source-based Relevance Claim**: when the aim is to advance the validity of a relevance claim using information from an external source. The source must be made explicit and is expected to be reliable and able to be checked.

Tool-- **Summary**: when the aim is to summarize the advancement in validity of a relevancy claim.

Stance-- **Testing**: when the aim is to test the validity of a claim of relevance.

Tool-- **Question**: when the aim is to interrogate the validity of a claim of relevance.

Tool-- **Problem**: when the aim is to problematize the validity of a claim of relevance.

Aim-- **Build community around relevance**: when the aim is to increase consensus around a statement of relevance

Stance-- **Solving**: when the aim is to create consensus around a statement of relevance.

Tool-- **My Relevance Affiliation**: when the aim is to connect/disconnect with a statement of relevance and its supporter/supporters.

Tool-- **Community-based Relevance Affiliation**: when the aim is to connect/disconnect a specific community with a relevance statement and its supporter/supporters.

Tool-- **Summary**: when the aim is to summarize the consensus around a relevance statement.

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Stance-- **Testing**: when the aim is to test the consensus around a statement of relevance.

   Tool-- **Question**: when the aim is to interrogate the consensus around a statement of relevance or its tests.

   Tool-- **Problem**: when the aim is to problematize the consensus around a statement of relevance or its tests.

Domain-- **Develop Ways-of-Knowing**-- When the comment seeks to solve a problem of how the community ought to create knowledge.

Aim-- **Design method**: When the aim is to improve the design of a method to create knowledge.

   Stance-- **Solving**: when the aim is to advance a design of a method.

      Tool-- **My Method**: when the aim is to advance a design using local knowledge.

      Tool-- **Source-based Method**: when the aim is to improve a design using knowledge coming from an outside source. The source must be made explicit and is expected to be reliable and able to be checked.

      Tool-- **Summary**: when the aim is to summarize previous comments on the design of a method.

   Stance-- **Testing**: when the aim is to test the design of a method to create knowledge.

      Tool-- **Question**: when the aim is to interrogate the design of the method.

      Tool-- **Problem**: when the aim is to problematize the design of the method.

Aim-- **Substantiate method**: when the aim is to validate or show that one method of creating knowledge is better than another.

   Stance-- **Solving**: when the aim is to argue for a particular methods claim.

      Tool-- **My Method Claim**: when the aim is to advance a claim resorting only to one's own knowledge.

      Tool-- **Source-based Method Claim**: when the aim is to advance a claim using some externally referenced source of information such as evidence or other source of knowledge. The source must be made explicit and is expected to be reliable and able to be checked.

      Tool-- **Summary**: when the aim is to summarize previous comments about the validity of a specific method claim.

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Stance-- **Testing**: when the aim is to test the validity of a method claim.

    Tool-- **Question**: when the aim is to interrogate the validity of a method claim.

    Tool-- **Problem**: when the aim is to problematize the validity of a method claim

Aim-- **Build community around a method**: when the explicit aim is to create consensus around a method of creating knowledge.

    Stance-- **Solving**: when the aim is to advance the consensus around a method.

        Tool-- **My Method Affiliation**: when the aim is to connect/disconnect with a method and its supporter/supporters.

        Tool-- **Community-based Method Affiliation**: when the aim is to connect/disconnect a specific community with a method and its supporter/supporters.

        Tool-- **Summary**: when the aim is summarize the consensus around a suggested method.

    Stance-- **Testing**: when the aim is to test the consensus around a method.

        Tool-- **Question**: when the aim is to interrogate the consensus around a method.

        Tool-- **Problem**: when the aim is to problematize the consensus around a method.

Domain-- **Improve KB Processes**-- When the comment seeks to solve a problem of discourse, from spelling or social norms to assessments in the process of knowledge improvement

Aim-- **Design KB Process**: When the aim of a comment is to improve the design of the KB process such as improve its internal consistency.

    Stance-- Solving: when the aim is to advance the design of the KB process.

        Tool-- **My KB Suggestion**: when the aim is advance the design of the KB process using local knowledge.

        Tool-- **Source-based KB Suggestion**: when the aim is to advance the design of the KB process using external information sources. The source must be made explicit and is expected to be reliable and able to be checked.

        Tool-- **Summary**: when the aim is to summarize the design of a suggestion to improve the KB process.

Stance-- **Testing**: when the aim is to test the design of suggestion to improve the KB process.

    Tool-- **Question**: when the aim is to interrogate the suggestion to improve the KB process or its tests.

    Tool-- **Problem**: when the aim is to problematize the suggestion to improve the KB process or its tests.

Aim-- **Substantiate position**: When the aim is to engage with the validity of the KB process based on some external system of benchmarks, from proper spelling and grammar to values and epistemologies.

  Stance-- **Solving**: when the aim is to advance the correctness of the KB process relative to external systems involved in KB discourse.

    Tool-- **My KB Suggestion Claim**: when the aim is to increase the correctness of the KB process with local knowledge.

    Tool-- **Source-based KB Suggestion Claim**: when the aim is to increase the correctness of the KB process with external knowledge sources. The source must be made explicit and is expected to be reliable and able to be checked.

    Tool-- **Summary**: when the aim is to summarize the argument as to the correctness of the suggestion to improve the KB process.

  Stance-- **Testing**: when the aim is to test the correctness of either a suggestion to improve the KB process or a test of it.

    Tool-- **Question**: when the aim is to interrogate the correctness of either a suggestion to improve the KB process or a test of it.

    Tool-- **Problem**: when the aim is to problematize the correctness of either a suggestion to improve the KB process or a test of it.

Aim-- **Build community around the KB process**: when the explicit aim is to develop consensus around a suggested KB process improvement.

  Stance-- **Solving**: when the aim is to advance a consensus around a suggestion to improve the KB process.

    Tool-- **My Affiliation**: when the aim is to connect/disconnect with a KB process suggestion and its supporter/supporters.

    Tool-- **Community-based Affiliation**: when the aim is to connect/disconnect a specific external community with a process suggestion and its supporter/supporters.

Tool-- **Summary**: when the aim is to summarize the state of the consensus around the process suggestion.

Stance-- **Testing**: when the aim is to test the state of consensus around a suggested process improvement.

Tool-- **Question**: when the aim is to interrogate a consensus around a suggested process improvement.

Tool-- **Problem**: when the aim is to problematize a consensus around a suggested process improvement