

# Supporting Discourse and Classroom Orchestration in a Knowledge Community and Inquiry Approach

by

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A thesis submitted in conformity with the requirements  
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Curriculum, Teaching and Learning  
Ontario Institute for Studies in Education  
Knowledge Media Design Institute  
University of Toronto

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## Abstract

This thesis presents a design-based research study of a new technology enhanced learning environment called Common Knowledge (CK), which supports students and teachers as they create socially shared notes, including tags, votes, and other forms of interactive knowledge construction. The research served to advance CK through 3 iterations, examining and extending the specific forms of technology, as well as the designs for activity sequences and teacher-mediated discussions. Two teachers participated, with their grade 5/6 students, in all three iterations. The teachers were actively involved in planning and designing the inquiry sequences, informing the designs of CK features, and giving feedback during and after the enactments. In early iterations, CK was employed as a stand-alone brainstorming and reflection tool, used to complement a broader inquiry activity where students collectively investigate a simulated phenomenon that is embedded within their classroom walls. In the final iteration, CK was employed as a scaffolding environment for a structured inquiry progression that included several phases for brainstorming, proposing topics, and open investigations. Discourse episodes are coded and analyzed to reveal patterns of interaction between teachers, students, and the shared knowledge base.

Each iteration of CK is examined in terms of the interplay between technology features, activity sequences, and the forms of teacher-guided discourse that emerge to support effective enactment. Because the inquiry topics, technology features and activity sequences vary from one iteration to the next, the teacher-guided discussions must play different roles and make use of CK note content and other knowledge elements in different ways. An activity systems approach is well suited to the interpretation of such interdependencies, as patterns of discourse can be understood as emerging to meet the system requirements, given the fixed set of technology affordances and well defined activity sequence. In each successive iteration, exciting technology features of CK were refined in response to critical evaluations of the previous enactment. New features were also added, including new tagging and data mining, which served to extend new forms of activity sequences. Initial iterations included simple applications as a supplemental brainstorming environment, where the final iteration employed CK to coordinate a structured progression from brainstorming through inquiry proposals and then open inquiry investigations.

Findings include the identification of a basic Reflect-Refocus-Release orchestration pattern, in which the teacher helps students to apprehend the progress or gaps in their inquiry, using content or patterns within the CK notes, engaging them in productive discussions, then releasing them to respond to the discussion appropriately. Additionally, four discourse orientations were observed within the Reflection phase of the pattern: (1) teacher reflection, (2) community (whole-class) reflection, (3) individual (student) reflections, (4) community (whole class) instruction. Within these orientations, teachers employed various discourse functions that served purposes of revoicing student ideas, norming the positions across the community, and casting students in various inquiry roles. The two teachers varied in how they employed these orientations, and also changed their patterns from one iteration to the next, reflecting the shifting task demands for discourse from one iteration to the next.

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## Chapter 1: Introduction

The most valuable asset of a 21st-century institution (whether business or non-business) will be its knowledge workers and their productivity (Peter Drucker, 1999; p. 79).

While technology and new media have become increasingly prominent in our daily lives, their meaningful application in K-12 classrooms has been much slower to unfold. Scholars like Cuban, Kirkpatrick, & Peck (2001), DiSessa (2001) and Prensky (2005) have addressed this phenomenon by asking first, what skills must school curriculum help students to achieve for success in the 21<sup>st</sup> century knowledge society? Employment and Social Development Canada (2013) lists, among nine Literacy and Essential Skills needed for work, learning, and life, the following: working with others, continuous learning, thinking, and computer use. These skills are also identified by the American Association of School Libraries in its “Standards for the 21<sup>st</sup>-Century Learner” (2007), which also includes sharing knowledge and creating new knowledge. The emphasis on knowledge creation and advancement is consistent with prior academic research conducted by Scardamalia and Bereiter (1996; 2006; 2010; Bereiter, 2002).

There has been a strong chorus amongst educators to engage students in "21st century learning," with many common themes. For example, Prensky (2012) calls for educators and parents to teach “digital wisdom”, to help mediate our increasing reliance on capabilities and cognition. Others have argued that learners must be supported to engage in sustained inquiry: identifying questions, encouraging multiple perspectives, connecting learning with personal experiences, addressing overarching themes, and fostering lifelong learning (Brown, 2009). Some researchers have proposed that technology-mediated inquiry may be an effective means of helping learners engage in personally relevant learning while helping them to develop new

technology and media skills, and ultimately become equipped for participation in the “knowledge society” (Jenkins, 2009; Slotta, 2010).

One defining aspect of 21st century learning that may bear on our design of new media is its highly collaborative nature (Jenkins, 2009), where individuals engage in social or collective forms of knowledge construction by contributing their ideas toward a common knowledge base. New media for knowledge creation or information collection have been inspired by “Web 2.0” technologies such as Wikipedia, YouTube, TripAdvisor, Reddit, and many other applications and online communities. While these environments were not originally designed for purposes of K-12 learning, researchers have begun to apply web 2.0 applications such as blogs, wikis, podcasting, online environments, social networks, and virtual worlds in their investigations (e.g., Arnold & Paulus, 2010; Churchill et al., 2009; Dede, 1995; Forte & Bruckman, 2006, 2007; Greenhow & Robelia, 2009; Greenhow, 2011; Hewitt & Peters, 2006; Lee et al., 2008; Peachey et al., 2010; Peters & Hewitt, 2010; Peters & Slotta, 2010; Petrakou, 2010; Thackray et al., 2010; Veletsianos & Navarrete, 2012; Wise et al., 2012; Wodzicki et al., 2012).

Such “knowledge media” provide learners with new models of communication and knowledge sharing (Shirky, 2008), making them well suited for curriculum that focuses on collaboration or knowledge building (Peters & Slotta, 2010). Some researchers have espoused a “Knowledge Community” approach (Bielaczyc & Collins, 1999; Slotta & Najafi, 2010, 2012), where learners engage in collective inquiry that helps develop a sense that they are making a contribution to a whole that will be “greater than the sum of its parts”. Scardamalia and Bereiter have argued for the need “to enculturate youth into this knowledge-creating civilization and to help them find a place in it” (2006; p. 97). In such collective inquiry approaches, learners develop new epistemological perspectives, taking initiative to build on the ideas of peers and

advancing knowledge within the community (Bielaczyc & Collins, 2006; De Jong, 2006). To support such modes of collaboration and collective inquiry, new forms of digital media and curriculum have been advanced (Slotta & Najafi, 2012) often blending asynchronous computer-mediated distributed learning systems with synchronous face-to-face (F2F) discussions (Bonk & Graham, 2006; Graham, 2009).

Within this overarching social context, there is a need for the design and study of technology environments that support collective inquiry and knowledge construction. These may take the form of note-sharing systems as advanced by several research programs (Tohyama & Miyake, 2011; Scardamalia, 2004; Scardamalia & Bereiter, 1996), collaborative concept maps (Kinchin, De-Leij, & Hay, 2005), wikis (Peters & Slotta, 2010), or other forms of media-enhanced knowledge construction. Recent studies have explored the possible role for audience response systems where students vote or add ideas using personal handheld devices, and the aggregate of all their inputs (i.e., a bar graph or table of responses) is shown on a large display at the front of the classroom (Crouch, Watkins, Fagen, & Mazur, 2007; Mazur, 1996). The teacher makes use of this student-generated data, in “real-time” (i.e., during the course of instruction) as a source of input to further instruction.

This doctoral research seeks to add to the research of technology environments for the support of classroom communities, with a focus on the support of discourse and interaction that complements collective inquiry. In particular, it will explore the changing role or activities of the teacher when such technologies are introduced. Developers of these new technology environments and approaches - certainly those from the research community - are typically seeking to introduce new forms of collaboration and discussion in the classroom, based on evidence of student ideas. Advocates of audience response systems, for example, hope to

produce compelling graphics of student ideas or opinions, which then catalyze evidence-based exchanges between teacher, students, and peers. Hence, new forms of media-supported knowledge construction and exchange can ideally lead to new pedagogical patterns. But how must teachers respond, adapt, and help to manage the successful introduction of such technology systems? What new forms of discourse are introduced to the classroom, necessitated by or concomitant with such technologies? If the classroom is seen as an activity system where teachers, students, materials, tools and environments interact according to established norms (i.e., goals, activities, and rules of behavior) how does such a system change or adapt to the introduction of new learning environment?

Specifically, I investigate the impact of a new technology environment on the teacher's *orchestration* of collective inquiry: how do new technology features and affordances necessitate or evoke new forms of discourse and activity patterns through which teachers help students develop and exchange ideas and make progress in their inquiry? Through a series of classroom trials, I explore a new form of note-sharing system for K-12 classrooms that includes enhanced functionality for student contributions as well as for teacher support. Working in close collaboration with an established research partnership for inquiry science, I developed several iterations of this new technology environment, called Common Knowledge (CK), which were integrated into carefully designed inquiry curricula for upper elementary science students. My work examines the design and performance of CK, the patterns of student activity, and the new forms of discourse that were evoked within the classroom.

Following an activity oriented design-based research approach, three iterations of CK are analyzed in terms of (1) the constituent technologies, (2) the specific sequences of activities that occurred, and (3) the discourse patterns that emerged within the classroom in association with

CK. For each iteration, CK is first analyzed in terms of its design: what forms of technologies, activity sequences, and discourse patterns did we envision, and how did these take form? Then, the actual classroom enactment is analyzed, to see how those technology, activity and discourse elements actually played out. Those analyses led to the identification of design issues that served to guide the design and development of the next iteration of CK. They also illuminated the nature of teacher-guided discourse, and how teachers employed the CK materials and functionality to advance inquiry and understandings within the student community. Through this effort, I hope to contribute to our understanding of how new technology environments influence the activity system of a classroom, leading to (intended and unintended) changes in how teachers coordinate activities and support students to develop ideas, interact with peers, and make progress on inquiry.

### **Theoretical Perspective**

This work is guided by a theoretical perspective of social constructivism, where learning is seen as a process of socially mediated knowledge construction that involves cognitive reorganization, and instruction that supports learners' construction of – rather than teachers' communication of – knowledge (Cunningham & Duffy, 1996). Social constructivism views learning as an intrinsically social process, in which an individual's knowledge structures and processes develop as a result of his or her interaction with peers, as moderated by discourse (Palinscar, 1998). Learning proceeds as individuals make connections between knowledge structures (Papert, 1993), seeking compatibility between their existing understanding and new ideas or experiences they encounter, continuously reflecting and trying to reconcile gaps or conflicts (Linn & Eylon, 2006). Social and individual interactions are mediated by semiotics (signs and symbols) including language, counting systems, algebraic symbolic systems, writing,

and graphical representations; these facilitate knowledge co-construction and internalization (Cunningham & Duffy, 1996; Jonassen et al., 1995; Vygotsky, 1962).

In social constructivism, the sociocultural context in which learning and teaching occurs is seen as intrinsic to the learning process (Palinscar, 1998). Each participant in a learning community holds his or her own cultural orientation, such that multiple perspectives must be recognized and negotiated (Cunningham & Duffy, 1996). Thus, the learning culture and social dynamics must be carefully considered, nurtured and accommodated by teachers. Social interactions, particularly those mediated by discussion, provide mechanisms for development of higher-order thinking (Palinscar, 1998; Wertsch & Smolka, 1994; Vygotsky, 1962). The teacher's role is critical to the scaffolding and navigation of discourse within the classroom, in support of productive thinking and consensus building (Palinscar, 1998). Hence social interactions, negotiation, and collaboration are seen as essential to the learning processes, as mediated by discourse (Cunningham & Duffy, 1996; Jonassen et al., 1995; Vygotsky, 1962). This research takes a social constructivist position that learning in classrooms progresses through discourse and collaborative knowledge construction, and that the teacher must orchestrate such processes as a facilitator and collaborator.

### **Collective Inquiry and Knowledge Communities**

Several research programs have examined a form of inquiry that emphasizes whole class engagement in the collective pursuit of common inquiry goals. Students work together to address an inquiry problem that may situate them in authentic contexts in which they engage in real-world problem solving practices (i.e. situated learning - Brown et al., 1989; Lave & Wenger, 1991), gradually progressing from the "legitimate peripheral participation" to more central engagement (Lave & Wenger, 1991; Wenger, 1998). Other research programs have attempted to

situate student learning in a context of a scientific inquiry community (Brown, 1994) in which they engage in “reciprocal teaching” (Palinscar & Brown, 1984). Brown and Campione’s (1994, 1996) “Fostering Communities of Learners” (FCL) focused on the advancement of the community’s collective knowledge through the integration of epistemic procedures within a sequence of inquiry stages, using shared discourse and culminating projects.

Scardamalia and Bereiter (1996; 1994) extended the notion of knowledge advancement in their “Knowledge Building” (KB) approach, conceiving of schools and classrooms as “knowledge building communities” where learners actively collaborate to produce knowledge as a “conceptual artifact”, and social processes focus on the continual improvement of these knowledge artifacts (Scardamalia & Bereiter, 1996). Slotta and his colleagues (Slotta, 2014; Slotta, Tissenbaum, & Lui, 2013; Slotta & Najafi, 2012) retain the notions of collective epistemology and knowledge construction, adding a layer of scripted inquiry (Fischer et al., 2013; Raes et al., 2012), in their “Knowledge Community and Inquiry” (KCI) approach. These theoretical positions, their research findings, and – where relevant – technology environments, will be discussed further in the review of literature (Chapter 2).

### **New Technology Environments for Collective Inquiry**

Recent advances in computing devices (e.g., handheld computers) and Internet functionality (e.g., Web 2.0) have introduced exciting new possibilities for technology environments that support collective inquiry. One affordance of these emerging technologies is their potential to externalize and persistently represent students’ thinking – especially important, given that knowledge community approaches such as FCL, KB, and KCI all rely on language and discourse to mediate learning interactions within the community.

Advances in computer supported collaborative learning (CSCL) research have yielded technologies where discourse plays a fundamental role of collaborative knowledge building (e.g., Group Scribbles - Roschelle et al., 2007; ConcertChat - Stahl, 2006; Mighty Mouse - Booth et al., 2002). Some CSCL environments have used the technology to “script” collaborative problem solving processes within a community (e.g., CollPad - Nussbaum et al., 2009). Other CSCL environments scaffold online discourse and add an element of crowd sourcing (e.g., “likes” for promising threads), for collaborative learning in a face-to-face environment (e.g., InterLACE - Coopey et al., 2013; PeppeR - Hewitt et al., 2013; hyperbolic tree-based visual discussion forum - Marbouti, 2012; Moodle - Dougiamas & Taylor, 2003; Knowledge Forum - Scardamalia, 2004). Inquiry discourse within knowledge communities can be viewed as a social process of meaning construction (Vygotsky, 1962). Such discourse may include argumentation (Bell, 2000; Kuhn, 1993), theory-building (Bereiter & Scardamalia, 2012), or explanation building (Sandoval & Reiser, 2004). However, the underlying goal of all these is the pursuit of deeper understanding and the epistemic practice of science (Nickerson, 1985).

In learning environments where the objective is to empower knowledge communities, there is typically a heavy reliance on teacher-guided oral community discourse (Slotta & Najafi, 2010). However, this places a serious burden on the teacher to orchestrate inquiry, continuously traversing online and face-to-face (F2F) environments, and guiding the discourse towards productive paths of inquiry. If technology for guiding inquiry and inquiry discourse should minimize teachers’ “orchestration load” (Dillenbourg, 2012), we must first understand how teachers guide such multi-modal inquiry and discourse, in order to design scaffolding technology to relieve some of their orchestrational load. Hence, there remains a need for research of discourse and activity sequences in technology-mediated inquiry environments. This observation has sparked the following research questions for this study:

1. How do features of the Common Knowledge technology environment support inquiry-oriented discourse and progress within the knowledge community?
2. How can a note-sharing environment such as Common Knowledge be integrated into a sequence of inquiry activities to support progress?
3. What forms of teacher-guided discourse are important to the successful application of community note-sharing environments in elementary classrooms?

### **Design-Based Research**

Design-based research (DBR) explores learning innovations in authentic classroom contexts, to understand the practice of these innovations, and thereby to improve theory and practice (Design-Based Research Collective, 2003). Innovation refinement and the formulation of design principles (Amiel & Reeves, 2008) emerges from iterative cycles of design, enactment, analysis, and redesign (Cobb et al., 2003; DBRC, 2003). This study will adopt a design-based approach, analyzing the design and enactment of several iterations of Common Knowledge, with attention paid to the role of technology in promoting activity sequences and fostering productive inquiry discourse.

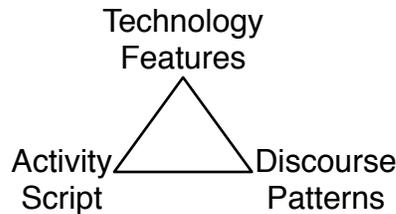
### **Activity Oriented Design**

Rooted in Vygotsky's concept of mediated action (i.e. that our interactions with the environment are mediated by tools and signs - 1978) and activity theory (Leontiev, 1978), the theoretical perspective of activity systems (Engeström, 1987) provides one way of understanding the interactions between students' learning, teacher orchestration, and the role of discourse in a technology enhanced learning environment.

The interpretation of technology innovations as activity systems allows researchers to negotiate the “ongoing interaction between the uses of computer systems, the practice of design, and the evaluation of designs produced” (Gay & Hembrooke, 2004; p. 2). In an effort to make activity systems more accessible and applicable to human-computer interaction (HCI) research and practice, Mwanza (2002) put forth the Activity-Oriented Design Method (AODM), which has been applied to explore learner experiences with technology (Mwanza-Simwami, 2011; Dolonen, 2009; Greenhow & Belbas, 2007). AODM comprises four methodological tools: (1) an “Eight-Step-Model” to help translate activity system components in relation to the activity being investigated, (2) an “Activity Notation” to facilitate the modeling and deconstruction of activity systems into sub-activity systems, (3) a “Technique of Generating General Research Questions” to examine learner interactions in sub-activity systems and identify contradictions, and (4) a “Technique of Mapping Operational Processes” to visually represent the transition of activities, sub-activities, components, component connections, and contradictions/problems (Mwanza-Simwami, 2011; Mwanza, 2002b).

Tool mediation is central to the notion of activity-oriented design, where tools are seen as created and transformed through human activity (Mwanza, 2002b). For example, the Common Knowledge (CK) environment can be interpreted as a mediating tool for inquiry activity, with community discourse as a necessary mediator. Together, these elements can be viewed as forming a Technology-Discourse-Activity system (see Figure 1), where analysis of this system can inform our understanding of the role of any two dimensions in the third, and inform our design of the next iteration of the Common Knowledge environment (including specific technologies, designed activity sequences, and expected patterns of discourse). The analyses presented in this thesis are organized around this structure, seeking to understand CK – including

student and teacher activities, knowledge products, and discourse – through the lens of activity systems.



*Figure 1.* Technology Discourse Activity system.

### **Structure of the Dissertation**

This dissertation is organized into six chapters. Chapter 2, Literature Review, provides the conceptual foundation for this research, motivating the present study in terms of prior work in knowledge communities and inquiry, as well as in discourse within the science classroom. Chapter 3, Methodology, explains the research approach, research context, study participants, and analysis plan. Chapter 4 analyzes the design and enactment of Iterations 1 and 2 of CK, evaluating the success, critiquing various features, for purposes of informing successive designs, and producing a qualitative description of the kinds of discourse that support teachers’ orchestration of the curriculum. Chapter 5 presents the third (culminating) iteration of the CK design, organized again according to the three dimensions of technology, activity, and discourse, but emphasizing a broader interpretation of the CK activity system. Finally, Chapter 6, Discussion and Conclusions, synthesizes the findings across all three iterations and critiques CK, including its applicability for collective inquiry and the need for future research.

## Chapter 2: Literature Review

The goal of this research is to understand how teachers can orchestrate the progression of activities within a Knowledge Community and Inquiry (KCI) curriculum, supported by a technology environment designed to capture and reflect student-driven inquiry. The Common Knowledge (CK) environment was developed specifically to support the KCI pedagogy, serving to represent student contributions in a persistent format that is accessible to students as a resource for further inquiry, and to teachers as a source of information about student progress. In recognition that teachers must bear a significant “orchestrational load” (Dillenbourg et al, 2013) in enacting any complex inquiry script, CK was developed to work in tandem with teachers, reducing this load, and supporting students and teachers alike.

The dissertation is concerned with how teacher-guided discussion emerge within the activity system that is a KCI enactment using CK – in response to the strengths, weaknesses, or affordances of the technology and curriculum script – with the purpose of moving the classroom community through the KCI script. The analyses in chapters 4 and 5 will focus on capturing the patterns of discourse that occur, and making connections to their dependencies on, or response to the particular technology features or curricular scripts.

This chapter will therefore review the prior literature relating to inquiry models, particularly relating to what is defined as a “knowledge community approach,” the role of scaffolding technology environments in the scripting and orchestration, and the role of teacher-guided discussions; with the goal of informing our understanding of the relationships between various factors, forces, or processes that emerge during classroom enactments of CK. Because this is design-oriented research, situated in a co-designed curriculum, the work makes no commitment to any particular form of discourse, or to the relationship between any form of

discourse and student learning outcomes. Rather, by following the technology, activities, and teacher-guided discourse through several iterations; it seeks to understand the role of teacher-guided discourse in ensuring that technology-based learning environments like CK can succeed in scaffolding their intended inquiry progressions.

### **Inquiry Frameworks**

In an effort to make science learning more engaging and accessible to students, educators have explored inquiry-oriented methods where students are engaged in active, often collaborative learning tasks; and students produce their own artifacts and reflect on their understandings (Bruner, 1961; Dewey, 1938; Papert, 1980). These notions are strongly aligned with constructivist approaches to learning (Slotta & Linn, 2009). Some researchers have advanced a notion of inquiry learning that mirrors the activities of scientists: formulating theories, testing hypotheses, critiquing evidence, engaging in scientific argument, and collaborating with peers (Kuhn, 1992; Linn et al., 2006; Loh et al., 2001; Piaget, 1976). Several studies have reported minimally guided inquiry has been found to be less effective or efficient than more guided or scaffolded forms (De Jong, 2006; Kirschner et al., 2006; Klahr & Nigam, 2004) while others report significant advances under less guided conditions (Scardamalia & Bereiter, 2006).

A proponent of learning-by-doing and situated learning, John Dewey saw cognitive perturbations as a way to spur learning opportunities (Dewey, 1938). He emphasized experience and reflection as central to learning (Dewey, 1938), and the shaping of individuals' growth into standard social activity through education and lifelong learning (Dewey, 1916). For Dewey, the social environment unconsciously affects our language habits, moral values, and perceptions of beauty; fostering social assimilation, societal norms, and social mobility (Dewey, 1916). Dewey asserted that ample "time, talk, and tools" are needed for learning and inquiry (Dewey, 1938),

and that the process of education involves continual reorganizing, reconstructing, and transformation (Dewey, 1916). Dewey, who started out as a science teacher, recognized the emphasis on facts and a lack of attention to the nurturing of scientific thinking. As a response to this, he recommended that inquiry be included in K-12 science education (Dewey, 1910). He conceived of students as active learners and teachers as facilitators of authentic learning experiences requiring reflection and collaboration. This eventually led to Dewey's (1938) proposed instructional inquiry model comprising six discrete phases: sensing perplexing situations, clarifying the problem, formulating a tentative hypothesis, testing the hypothesis, revising rigorous tests, and acting on the solution.

Building on Dewey's ideas about inquiry and Piaget's notions of cognitive development, Karplus and Thier (1967) proposed a "learning cycle" for the six-year science curriculum of the Science Curriculum Improvement Study (SCIS) aimed at the development of scientific literacy (Bowyer & Linn, 1978). This learning cycle became the teaching approach of SCIS curriculum: (1) exploration – students individually explore a phenomena, (2) invention – teacher invents a concept and introduces corresponding new terms to students, and (3) discovery – students discover the concept through multiple learning activities in which they apply the concepts to related but new experiences (Karplus & Lawson, 1974).

The designers of SCIS conducted a number of studies that generally support the use of SCIS/learning cycle developed by Karplus and Their. Abraham and Renner (1983) conducted seven experiments on six high school chemistry classes to test the form, sequence, and necessity of each learning cycle phase. Impact on students' achievement in conceptual understanding and attitudes were studied through chemistry topics of: physical and chemical change, conservation of weight and atoms, simple chemical reactions, redox reactions, reaction rates, heat laws, and

Arrhenius acids and bases. Abraham and Renner concluded that activity sequencing is important – students embraced the laboratory instructional format for the learning cycle, and that teachers should not expect the use of readings with learning cycles to be effective. In a later study, the same authors altered the sequencing of the three phases, in two high school learning cycles of chemistry. Students' content and attitude measures led the researchers to conclude that it is important to maintain the normal learning cycle sequence (i.e. explore, invention, discovery) for content knowledge achievement (Abraham & Renner, 1986). In another study to test the importance of various phases within the learning cycle, one or two phases were intentionally omitted from two high school physics classes and a third “control” class experienced the full three-phase learning cycle, while learning about: (1) the relationship between weight and gravity, and (2) Ohm's Law (Renner, Abraham, & Birnie, 1988). All phases were found to be necessary, leading to greater conceptual understanding; and that interestingly, stresses the learning cycle's combination of student investigations and discussions between teacher-student and student-student, to coordinate scientific experience into a logical system.

The SCIS learning cycle has been found to have positive effects on the learning of various science topics, including: grade 1 classification of material objects (Linn & Peterson, 1973), grade 1 conservation (Haan, 1968; Stafford, 1969), grade 2 serial ordering (Almy, 1970), grade 4 relative position and motion (Battaglini, 1972), grade 5 energy sources (Linn & Thier, 1975), grade 5 application of science processes (Weber, 1971), and grade 6 scientific literacy (Bowyer & Linn, 1978). SCIS teacher feedback indicated they perceive that the SCIS learning cycle would work well for handicapped elementary learners integrated into the regular classroom for activity-centred science (Atwood & Oldham, 1985).

SCIS was extended in the late-1980s by the Biological Sciences Curriculum Study (BSCS - Bybee et al., 2006) into the “5E” Instructional Model that is currently in wide use, and comprises: (1) engagement – connects to students’ past experiences, exposes students’ misconceptions, and causes puzzlement; (2) exploration – teachers facilitate concrete activities through which students formulate concepts, processes, and skills; (3) explanation – teachers ask students to explain their engagement and exploration experiences, then the teacher connects these directly to scientific or technological explanations; (4) elaboration – transfer concepts via related new activities, with generalization as the goal; and (5) evaluation – formal assessment of students’ understanding. Phases of this model are intended as a framework for a yearlong program, a curriculum unit, or as lesson sequences.

As an updated version of the SCIS model, the BSCS 5E Instructional Model became the pedagogical framework upon which the study developed a K-6 science program incorporating health and technology, a middle school science and technology program, a high school biology program, and a general science inquiry program (Bybee et al., 2006; Dougherty & Miller, 1998; Bybee & Landes, 1990). This model has also been used in the development of a middle school health education series, as well as 16 health and science modules spanning grades 1 to 12 for the Office of the Science Education at the National Institutes of Health. All BSCS programs are field-tested nationally, and then revised before publication, to ensure the activities are optimized for the classroom and the improvement of students’ conceptual understanding (Bybee et al., 2006). Research on the BSCS 5E Model either compare this approach to more traditional approaches in the teaching of a given science topic (Akar, 2005; Ebrahim, 2004; Lord, 1997), or compare the fidelity of BSCS 5E curriculum implementation (Bybee, 2009; Taylor, Van Scotter, & Coulson, 2007). The findings support the effectiveness of the 5E model as an instructional

approach to inquiry, and note the essential role of teacher professional development to support their understanding of curriculum materials and the instructional model (Bybee & others, 2009).

The 5E inquiry cycle has prompted others to extend the framework. One example is Eisenkraft's (2003) proposed expansion of the 5E model into a 7E model, in which the Elaborate and the Evaluate phases are expanded into three components – elaborate, evaluate, and extend. The goal was to emphasize the importance of eliciting prior knowledge and conceptual transfer. Thus the 7E model comprises: elicit, engage, explore, explain, elaborate, evaluate, and extend. Dunkhase's (2003) 6-phase Coupled-Inquiry Cycle is another inquiry framework that builds upon the BSCS 5E model, and incorporates aspects of problem solving models to balance heavy curriculum mandates within limited instructional time, and learner-centred inquiry. The 6-phase Coupled-Inquiry Cycle comprises: (1) invitation to inquiry – teacher introduces a motivator activity to “hook” student interest in the topic; (2) guided inquiry – teacher directs students towards specific curriculum objectives, (3) “explore on your own” – students generate their own questions for investigation through independent exploration; (4) "open" inquiry - students' questions are negotiated and chosen for investigation, then students design, conduct, interpret and present the study; (5) inquiry resolution – teacher guides students to “cognitive closure” about science concepts that fulfil curriculum objectives; and (6) inquiry assessment – encompasses continuous formative assessment throughout the cycle and summative evaluation at cycle's end, ideally with an authentic performance component. Teacher feedback from professional development workshops utilizing the Coupled-Inquiry approach indicated they were more likely to apply inquiry in their classrooms than participants of inquiry workshops focused on student-centred “open” inquiry models (Dunkhase, 2003).

White and Frederiksen (1998; White, 1993) drew from research on the metacognitive model of Inquiry Cycle and the metacognitive process of Reflective Assessment (i.e. student self- and peer-assessment), to create a 5-step Inquiry Cycle for their ThinkerTools Inquiry Curriculum in which students: (1) question – formulate their own investigable research question about a topic they want to understand, (2) predict – generate multiple hypotheses related to their research question, (3) experiment – design and perform experiments using computer simulations and real world materials to investigate their research question, (4) model – use data analysis results to construct a conceptual model that would predict and explain their findings, and (5) apply – investigate the generalizability of their model by applying it to different situations, which will yield model limitations leading to new research questions and the start of a new Inquiry Cycle. The pairing of each Inquiry Cycle phase with the Reflective Self-Assessment Process scaffolds students' metacognition, and enables them to evaluate their on-going progress as they develop their inquiry skills and knowledge. The ThinkerTools curriculum encompasses 7 modules of Newtonian force and motion topics, and scaffolds middle school students within each Inquiry Cycle phase, as they work in the ThinkerTools simulation environment to interact with and create new models of Newtonian force and motion (White & Frederiksen, 1998).

Barbara White and her colleagues (White, Shimoda, & Frederiksen, 1999) then re-conceptualized this into a 6-step cycle, where students: (1) question – formulate a research question, (2) hypothesize – generate multiple predictions, (3) investigate – design and perform experiments to test their hypotheses using computer simulations such as the ThinkerTools Newtonian mechanics simulation software, (4) analyse – scrutinize the resulting data for patterns, (5) model – formulate a generalizable law and causal model from their findings, and (6) evaluate – apply resulting laws and causal models to real-world situations to determine limitations, which lead to new research questions and the start of a new Inquiry Cycle (White et

al., 1999). This 6-step Inquiry Cycle has been used with upper elementary and middle school students conducting Newtonian physics investigations within the SCI-WISE (White et al., 1999) and the Inquiry Island (White et al., 2002) scaffolded inquiry technology environments.

### **Scaffolding Metacognition**

The coupling of inquiry frameworks with technology-enhanced learning environments has incorporated cognitive and metacognitive inquiry scaffolds, guiding learners through the inquiry process and in some cases, prompting students in response to their progress. Descending from the content-embedded ThinkerTools project, the SCI-WISE environment was designed around the conjecture that middle school students could “learn how to learn” through agents that model social, cognitive, and metacognitive expertise in inquiry, reflection, and self-improvement; and by being engaged in the evaluation and modification of these models (White et al., 1999). Beginning from a “seed system”, students created and revised theories, and designed “intelligent advisors” that scaffolded and coached them through collaborative inquiry and critical reflection processes. SCI-WISE offered a composing environment with which students could capture their reflections about their inquiry process, and software agents (e.g., Task Advisors – Questioner, Hypothesizer, Investigator, Analyzer, Modeler; Cognitive Advisors – Inventor, Planner, Representer, Reasoner; Social Advisors – Communicator, Collaborator, Debator, Mediator) that could advise and guide students as they engaged in collaborative research projects and reflected upon their inquiry practice (White et al., 1999). Among the findings of the SCI-WISE study, there was one finding regarding the scaffolding of metacognition: reflective assessment brings metacognition explicitly into the classroom’s social processes thereby further contributing to the development of metacognitive knowledge and skills (White et al., 1999; White & Frederiksen, 1998).

White and her colleagues next developed Inquiry Island – an environment that included a community of advisors to guide 6 phases of inquiry and reflection (i.e. question, hypothesize, investigate, analyze, model, and evaluate), and support self- and peer-assessment. Inquiry Island was an advancement on SCI-WISE – retaining the use of software agents to guide and promote scientific inquiry and reflective learning, now personified and tailored for each inquiry task. Students also had access to their Research Notebook on Inquiry Island, which is organized according to the 6 stages of the Inquiry Cycle. Each page scaffolded students through an Inquiry Cycle stage, was guided by a Task Advisor, and enabled students to self-assess and reflect on their inquiry process as they worked on a page (White et al., 2002). As students worked in a “task artifact” (e.g., the “Research Notebook”), they could consult any of the modifiable agents on the advisory team. Inquiry Island investigators found that, by making use of such communities of software advisors and then reflecting on the strategies suggested by a particular advisor, students could actually learn about inquiry learning and how to improve their own skills (White et al., 2002).

Herrenkohl and her colleagues (2011) expanded on the work of Inquiry Island in a new Web-based version called the Web of Inquiry (WOI) where students were guided through a 6-phase scientific inquiry cycle (i.e. question and theorize, hypothesize, investigate, analyze, synthesize, extend) to develop and test their theories, learn scientific language norms, and engage in self- and peer-assessment (Herrenkohl et al., 2011). Students worked within an inquiry task structure and were guided through the inquiry process by a community of “software advisors”. WOI was developed with the goal to support upper elementary and middle school students and teachers to coordinate claims with evidence throughout hypothesis generation and testing. Like Inquiry Island, WOI scaffolded students to do self- and peer-assessment tasks aimed at supporting students’ development of metacognitive skills “for questioning links between

theories, hypotheses, data collection methods, evidence, and returning back to initial theories and claims” (Herrenkohl et al., 2011; p. 5). In classrooms that completed two WOI projects, students’ first and second WOI project scores were compared, and significant or nearly significant improvements were found in six areas: Asking Questions, Developing Descriptions, Explanations and Models, Analyzing Alternative Explanations, Skepticism, Extending your Research, and Communication (Herrenkohl et al., 2011).

The ExplanationConstructor (EC) electronic journal, used in conjunction with BGuILE curriculum (discussed in the next section, “Scaffolded Inquiry: Technology-Enhanced Learning Environments”), was an epistemic tool to support students’ ongoing formulation and evaluation of explanations through their inquiry (Sandoval & Reiser, 2004). Influenced by cognitive apprenticeship (Collins, 2006) and situated learning (Lave & Wenger, 1991), EC developed discipline-specific “explanation guides” that suggested investigative actions and helped students monitor their progress. The design of EC was based on 5 principles:

1. Frame inquiry as an endeavor to explain phenomena, with an emphasis on the product’s form
2. Link Explanations to Specific Questions
3. Represent Theories as Explanatory Frameworks
4. Link Evidence to Causal Claims
5. Structured Opportunities for Epistemic Reflection

This research engaged students in comparing and critiquing explanations, similar to the epistemic practices of scientists. It showed that by scaffolding the construction and critique of explanations, it is possible to make the implicit aspects of scientific reasoning more explicit. Use of the ExplanationConstructor with grade 9 students engaged in a 4-week BGuILE evolution unit

yielded peer-to-peer dialogue shaped by EC's persistent epistemic representations, which were grounded within the discipline. Although EC provided inquiry guidance congruent with the BGuILE framework and to EC's design principles, students varied in their readiness to use the tools, and hence they varied in the tool interactions. Students also varied in how well they explained the problems, suggesting that explanation evaluation plays a prominent role in supporting student understanding of the problems they investigate and their constructions of scientific explanations. Furthermore, students assessed their inquiry performance leniently and reflection prompts did not generate substantive reflections about explanation quality. These findings prompted the researchers to revise EC, so that potential evidence is immediately visible, and data may be cited in students' explanations. Researchers and the teacher also co-developed a rubric for good explanations. This new iteration of EC was used with 4 high school biology classes engaged in 4-week evolution BGuILE curriculum. This second study showed that students' peer assessments were more focused explanation content, than their self-assessments. Furthermore, researcher support and the explanation rubric had a positive impact on students self-assessing their explanations in epistemic terms. Finally, varying task structure affected student use of epistemic criteria.

The environments reviewed above provided cognitive and metacognitive scaffolding to guide students through the inquiry process, helping them learn specific content matter, while emphasizing metacognitive aspects of scientific inquiry. Students typically worked in small groups or individually, within the parameters of their particular inquiry trajectory. The next section reviews a strand of the research literature that explored inquiry in a more social context of "learning communities" – where the classroom as a whole is imbued with epistemic values and practices that reflect a more collective approach to the advancement of knowledge.

## **Scaffolding Inquiry: Technology-Enhanced Learning Environments**

The various inquiry frameworks and environments discussed above were developed to help guide student-centred explorations that lead to constructivist learning. Students typically define their own questions, and are then guided by teachers or even peers to investigate those questions, and reflect on outcomes. Such approaches hold promise for 21<sup>st</sup> century science instruction, but are challenging to develop and implement (Bybee et al., 2009). Often, inquiry-oriented instruction employs “scaffolding technology environments” to support student actions and interactions (Linn & Eylon, 2006; Slotta & Linn, 2009). These environments typically incorporate technology systems designed around pedagogical principles to support the epistemological forms that are of interest to those who develop and research the systems.

The notion of scaffolding was advanced to describe cognitive, social or technological supports that help learners to solve problems, or conduct inquiry activities of which they would be incapable without some form of support (Wood et al., 1976). Descending from Vygotsky’s (1978) notion of the ZPD, scaffolds may take the form of constrained or graduated tasks, structured learning materials, direct teacher guidance, or technological guidance. In principle, scaffolds could be “faded” as learners gain skill and competence to achieve the tasks independently (Collins, 2006). Although much of the research on scaffolding has focused on supporting individuals in their learning (Collins, 2006; Linn & Hsi, 2000), researchers have argued for the importance of scaffolding social processes as well (e.g., Kolodner et al., 2003).

“Scaffolded inquiry” refers the guiding of learners through specific activities, social exchanges, and progressions by using carefully constructed learning materials or technology environments that productively constrain student interactions, and reinforce epistemic commitments (Linn & Hsi, 2000; Slotta & Linn, 2009). Quintana et al. (2004) defined a

framework for the design of scaffolding technology environments, including 20 strategies to support sense-making, inquiry process management, articulation, and reflection. This section reviews technology environments from two genres: (1) those designed to support specific inquiry frameworks or progressions, and (2) those designed to support a curriculum topic.

Content-embedded inquiry environments have been developed to scaffold inquiry in specific domains. For example, ThinkerTools (Frederiksen & White, 1992; White, 1993) – discussed in the previous section – engaged sixth graders in a 5-phase inquiry process (i.e. question, predict, experiment, model, and apply) within a series of interactive Newtonian force and motion simulations, where they constructed causal models about how the motion of objects was affected by forces, and developed awareness of the cognitive and social processes of inquiry. This study found that sophisticated inquiry-based science can be taught in urban schools, that learning inquiry skills improves conceptual science learning and transfer of knowledge to new situations, that there are no gender differences in learning scientific inquiry (but there are pre-existing gender differences in science knowledge), and that inquiry and reflective assessment should be introduced early in the school curriculum. White and Frederiksen (1998) argue that making inquiry processes explicit helps to demystify the nature of inquiry and enables students to see they are capable of doing it. Further, they argue that incorporating teacher assessment of students' inquiry skills helps to avoid teacher bias against lower achieving students and female students, and that bringing metacognition explicitly into the classroom's social processes supports the development of metacognitive knowledge and skills (White & Frederiksen, 1998).

BGuILE (Biology Guided Inquiry Learning Environments) consisted of curricular units that engaged 9<sup>th</sup> grade learners in observational investigations and theory articulation of causal explanations based on primary data about evolutionary biology. Students were provided with

primary data and analysis tools, as well as supports for synthesizing explanations; enabling them to identify organisms and collect data observed in their schoolyard. BGuILE's approach to scaffolding inquiry was to make explicit the connections between: (1) general inquiry goals, (2) disciplinary theories, and (3) investigation strategies. BGuILE researchers investigated the role of discourse in student inquiry by incorporating both informal and structured discussions throughout the inquiry activities "to provide opportunities for reflection and for sharing and critiquing ideas" (Reiser et al., 2001; p. 3). In one middle school unit of BGuILE curriculum, middle school learners investigate a crisis in a Galapagos island ecosystem to learn about natural selection and ecosystems over a 7-week period. The unit begins with a set of introductory activities that provide background knowledge and engage students in brainstorming activities that reveal their prior knowledge of island ecosystems. Next, learners are connected to the problem in the investigation – a crisis on a Galapagos Island, and scaffolded to learn about BGuILE software and ecosystem data. The next phase engages student teams in the investigation of a data record (including field notes) of the island's environmental characteristics, plant and animal species, as well as the morphology and behaviour for the threatened finch population. Students may use this dataset to compare species populations, look for changes across time, and identify any possible trends and relationships that may explain the declining finch population. The unit concludes with student presentations and a culminating class discussion.

The Explanation Constructor software was developed to support students working with BGuILE, allowing them to gradually construct their explanations during their investigation. Four design principles guide BGuILE's curriculum and technology: (1) structure inquiry around explanatory goals, (2) embed the structure of theories and strategies in the tools students use and the artifacts they create, (3) integrate classroom and technology-supported learning activities,

and (4) support ongoing reflections within the structure of the learning activities (Reiser et al., 2001). The Explanation Constructor research found that learning about scientific process should be complemented by a focus on discipline-specific instruction and scaffolding. Recognizing the tension between tools that are discipline agnostic, and well-designed environments targeted to specific disciplinary topics, the BGuILE researchers suggest “that the field needs to explore the design strategies for crafting each type of support, ways to document what each can achieve, and then compare the design tradeoffs” (Reiser et al., 2001; p. 28).

The Progress Portfolio software was designed to support students’ development of inquiry skills and to help nurture them into “reflective inquirers” (Loh et al., 2001). Loh and his colleagues view Reflective Inquiry as encompassing effective inquiry strategies and reflective activities, where students are scaffolded to engage in three inquiry activities: (1) ongoing documentation of progress, (2) reflective monitoring of progress, and (3) effective communication of process and results to others. The Progress Portfolio enabled students to create a record of their progress, which served as “objects of reflective conversations” and “objects of reflective actions”. Furthermore, the Progress Portfolio was intended to implicitly provide a task model for reflective inquiry. For example, the Data Camera tool within the Progress Portfolio supported progress documentation by allowing students to capture a picture of their investigation, then insert it into a customizable “page” and explain it using text fields on the page or “sticky notes”. Students could cluster pages into thematic folders, to support reflective monitoring of their inquiry progress. Presentation tools in the Progress Portfolio allowed students to review their work and capture pages into a slide presentation. Case studies of high school physics students’ use of the Progress Portfolio suggests that students need to understand the nature and goals of the final product to effectively document their inquiry progress, this documentation needs to be an active student process wherein self-monitoring may lead to

strategy revision, and that the process of creating a final product is as important as the presentation itself for fostering reflection (Loh et al., 2001).

The BioKIDS curriculum (Songer, 2006) engaged 5<sup>th</sup> and 6<sup>th</sup> graders in 3 elements of inquiry reasoning: evidence-based explanations, data analysis, and hypothesis/prediction formulation. BioKIDS utilized a handheld environment called CyberTracker and a reference guide called Critter Catalog to scaffold students' collection of observations about insects and animals in their schoolyards. Students were scaffolded by CyberTracker and other web-based technologies to conduct a structured set of curriculum activities that progressed through a four-stage inquiry framework: engage, explore, explain, and synthesize. Two findings from the Biokids study was that systematic guidance is required in helping students to develop increasingly complex ideas, as well as a systematic approach to revisiting and deepening understandings.

The Web-Based Inquiry Science Environment (WISE) was developed to provide students and teachers with scaffolding as they conduct well-designed inquiry projects that include scientific visualizations, argumentation tools, and critical reflection about evidence. WISE projects address science standards, and are co-created through partnerships with subject-matter experts, teachers, and educational researchers (Linn & Slotta, 2000). Projects typically take 1 of 3 forms: (1) critique – evaluate resources for credibility/relevance, (2) scientific debate – construct/evaluate evidence-based arguments, and (3) design – apply scientific ideas to design a solution to a problem (Slotta & Linn, 2009). All WISE curriculum is designed to support the 4 tenets of Scaffolded Knowledge Integration: (1) make science accessible, (2) make thinking visible, (3) help students learn from one another, and (4) foster autonomy and lifelong science learning. When synthesized into well-designed learning activities, these tenets promote “the

dynamic process of linking, connecting, distinguishing, organizing, and structuring ‘models’ of scientific phenomena...We use the term model to refer to patterns, templates, views, ideas, theories and, visualizations” (Linn, 2000; p. 783).

### **Scaffolding Communities of Learners**

Constructivist theorists have placed a high value on the culture of learning, such as Vygotsky’s (1978) notion of “syncretic schemata”, where socialization is critical to the development of critical thinking skills that occur through selection, reduction, and mutual adaptation of knowledge abstractions. Collins, Brown and Newman (1989) proposed a model of “Cognitive Apprenticeship”, where students are guided in developing: (1) cognitive skills and processes, (2) expert processes, and (3) learning in context; with the ultimate goal of developing expert processes of handling complex tasks such as reading, writing, and mathematics. Teachers make explicit to students the expert processes of the task at hand, situate tasks in authentic contexts, and vary the context – making sure to articulate the commonalities – to promote transfer of learning (Collins, Brown, & Holum, 1991). Four dimensions of learning environments facilitate cognitive apprenticeship experiences: content, method, sequencing, and sociology; where each dimension is deliberately scaffolded and gradually faded (Collins, 2006).

Collins and his colleagues point to Reciprocal Teaching of reading (Palinscar & Brown, 1984), Procedural Facilitation of writing (Scardamalia & Bereiter, 1985; Scardamalia, Bereiter, & Steinbach, 1984), and Shoenfeld’s method of teaching mathematical problem solving (1985, 1983) as successful examples of basic cognitive apprenticeship methods (Collins, Brown, & Holum, 1991; Collins, Brown, & Newman, 1989). In all three approaches, students begin to view the domain as one in which they are required to be critical and reflective – not just of the subject-matter, but also of their own approach to the task. Teachers make expert processes

explicit initially through modeling and thinking aloud – again, not just about the subject-matter, but also explicitly explaining their process. As students gradually gain competence in the processes, teachers can fade the directness of their support - progressing from modeling, to coaching, to scaffolding – gradually providing more autonomy to students. Some authors (e.g., Lenski & Nierstheimer, 2002; Silliman & Wilkinson, 1994) have pointed to a distinction between “directive scaffolding,” that centers on teacher-directed instruction, and “supportive scaffolding,” that emphasizes learner-centred experiences in which students co-construct their inquiry approach with an expert or a more knowledgeable peer.

Some studies have investigated the effectiveness of the cognitive apprenticeship approach in classroom environments. Pre-school children who received scaffolded instruction in completing abstract tasks with building blocks, outperformed their counterparts who received no instruction, on a posttest 3 days later with completion rates of 90.7% and 33.3% respectively (Coltman, Petyaeva, & Anghileri, 2002). Grade 5 science students used a computer application to complete a concept mapping activity as a strategy to understand science texts, where the task varied in the amount of scaffolding; and students were assigned to one of three experimental groups: map-correction group (revise an expert-generated concept map), scaffold-fading group (complete an expert-created concept map template), map-generation control group (create a concept map from scratch). Post-test results demonstrate that the map-correction group achieved the most gains in text comprehension, and both the map-correction and scaffold-fading groups achieved better text summarization than the control group (Chang, Sung, & Chen, 2002). On a posttest at the end of the instruction, grade 7 students who learned about causality through a cognitive apprenticeship approach, outperformed their counterparts who received a causality lecture and practice activities, but did not significantly differ from their counterparts on a far-transfer task two weeks later (Hendricks, 2001).

The principles of cognitive apprenticeship have informed pedagogical approaches concerned with situated learning (Collins, 2006). Situated Learning emphasizes the interrelationships between “agent and world, activity, meaning, cognition, learning, and knowing” (Lave, 1991; p. 67); and claims that learning, thinking, and knowing are socially generated by people engaged in “activity in, with, and arising from the socially and culturally structured world” (Lave, 1991; p. 67). Learning is embedded within authentic contexts in which students engage in real-world problem solving practices (Brown et al., 1989; Lave & Wenger, 1991).

Examples of educational research projects that have been influenced by situated learning include the notion of anchored instruction (Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990), which was illustrated by the Jasper Woodbury series - a set of 20-minute videos that situated middle school students in mathematical problem solving scenarios such as devising a rescue plan for a wounded eagle, or creating a business plan for a school fair. Such problems were designed to span several days (Cognition and Technology Group at Vanderbilt, 1997) and engage students in authentic inquiry practices

By engaging in shared project-based experiences, students’ participation in a “Community of Practice” shapes their identities while giving “structure and meaning to knowledgeable skill” (Lave, 1991; p. 74), where community members have a sense of ownership and mutual dependency (Collins, 2006). Through “Legitimate Peripheral Participation” (LPP) learners gain implicit and explicit knowledge through their participation/observation from the periphery – a process similar to apprenticeship, where apprentices gradually progress from peripheral to central participation and are fully immersed in the culture of the learning

community. Researchers have investigated the LPP approach in varied contexts, including mentorship into a profession/discipline and language learning.

Health librarians have used the LPP framework to develop a competency continuum to assist trainees and their mentors map the development of trainee knowledge and skills, as they progress towards mastery and full competence (Clarke & Thomas, 2011). A study of LPP in regard to informal learning and the relationship between PhD students and their supervisors found that engineering students and social sciences students referred to their supervisors less and less as they progressed in their programs, gradually shifting their reliance to senior students. Features of informal learning in which academic supervisors first scaffolded and then gradually faded were: initiation, inter-student collaboration, and writing (Hasrati, 2005). Another study using LPP to guide selection and preparation of school principals for mentoring roles made four recommendations for designing internships: (1) university pre-service programs should design internships using elements of LPP, (2) mentors must be carefully selected by university and school district administrators, (3) universities should help selected principal mentors develop mentoring skills, (4) universities must ensure mentor principals have a firm grasp of the leadership theories taught in coursework and designate experiences interns should have under their mentorship (Williams, Matthews, & Baugh, 2004).

Another approach related to Communities of Practice is that of “Communities of Learners,” where the goal is “to lure students into enacting roles typical of a research community” (Brown, 1994; p. 7). One early approach was known as “reciprocal teaching” (RT) – a reading comprehension approach designed to engage individual learners in learning communities organized as small heterogeneous groups who questioned, clarified, summarized, predicted, and monitored their own reading progress (Palinscar & Brown, 1984). Group

consensus about the meaning of texts is mediated through discussion, since “thinking is externalized in the form of discussion” (Brown, 1994; p. 7) – emphasizing the importance of discourse in learning (Bakhtin, 1986; Bruner, 1991; Vygotsky, 1962; Wertsch & Smolka, 1994). Palinscar and Brown’s (1984) comparison study of 24 grade 7 students with reading comprehension difficulties who participated in RT, showed significant and sustained improvement in summarizing, questioning, and clarifying; as well as gains on comprehension. A second study of 21 middle school students replicated much of these findings (Palinscar & Brown, 1984). Others have found the RT approach to be an effective reading comprehension program for elementary students (Carter, 1997; Frances & Eckart, 1992; King & Johnson, 1998; Meyer, 2010; Rosenshine & Meister, 1994; Williams, 2010). However, some studies have found that RT does not work for all students (Moore, 1988).

### **Classrooms as Knowledge Communities**

Calling for a reconceptualization of schooling to foster “progressive problem solving”, where students develop skills in ways similar to experts, Scardamalia and Bereiter (1994) have conceived of schools as “knowledge building communities” where learners actively collaborate to produce knowledge as a “conceptual artifact”, and social processes focus on the continual improvement of these knowledge artifacts. Other scholars have described the general notion of classrooms as “knowledge communities,” referring to pedagogical perspective that treats the classroom as the lens of activity, with an emphasis on collective epistemology and inquiry-oriented discourse (Bielaczyc & Collins, 2006; Slotta & Najafi, 2010; Bielaczyc et al., 2011).

The knowledge community perspective places students’ sense of participation in a classroom community, and the advancement of their community’s knowledge at the center of any pedagogical treatment. This will influence the design of materials, resources, activities,

tools and scaffolds, and entails an epistemological commitment to helping students learn to value and build upon the ideas of their peers. The outcomes of any knowledge community approach are not necessarily measured by student performance, but rather by the level and nature of the discourse within the community, the growth of the knowledge, and engagement of students in helping to build on knowledge of their peers. Slotta & Najafi (2010) articulated three elements that are common to any knowledge community: (1) distribution of responsibility for advancement of knowledge within the community, (2) a shared or collective knowledge base that can be accessed as a resource and improved upon through inquiry (3) technological and pedagogical scaffolding for inquiry and discourse processes. Drawing on economics, organization theory, and historical scientific events, Bielaczyck & Collins (2006) observed seven characteristics of “knowledge-creating communities”: (1) sharing ideas, (2) multiple perspectives, (3) experimentation, (4) specialization, (5) cognitive conflict and discussion, (6) reflection, and (7) synthesis.

Any knowledge community approach will need to address student epistemology, supporting a shift away from the notion of individual-as-learner to one of “collective cognitive responsibility” (Bereiter & Scardamalia, 2010). Students will require support to understand the activities within their classroom as being in service to the progress of their local (classroom) community. Such forms of learning will likely include a greater level of sharing and exchange of knowledge, negotiation of approaches, and resolving of conflict than more traditional pedagogical approaches, and can be mediated through “shareable epistemic artifacts” (i.e. texts, graphs, models). Such mediation requires an individual to synthesize ideas at the edge of their understanding, where the artifacts are subsequently used to generate further inquiry (Bielaczyck et al., 2011).

## **Knowledge Building**

Knowledge Building (KB) is a prominent example of the knowledge community approach and has been advanced as a powerful way of supporting a collective epistemology and idea-centered approach to learning (Bielaczyck, 2011; Hmelo-Silver & Barrows, 2008; Gilbert & Driscoll, 2002; Stahl, 2000; Scardamalia & Bereiter, 1996). Scardamalia and Bereiter call for “the democratization of innovative capacity” (Scardamalia & Bereiter, 2010; p. 11) and maintain that schools should adopt a culture of collaborative knowledge advancement to give children the opportunity to participate in today’s knowledge society and prepare them for the future (Bereiter et al., 1997; Bereiter, 2002; Bereiter & Scardamalia, 2010, 2006).

Whereas schools traditionally adhere to a pedagogical model of learning through tasks and activities, in knowledge building all strategic cognitive activity is turned over to the students (Bereiter, 2002). Enculturated with a sense of “collective cognitive responsibility” (Scardamalia, 2002), learners “take responsibility for knowing what needs to be known and for insuring that others know what needs to be known” (Scardamalia, 2002; p. 2). This process has been supported by the development of an asynchronous discourse environment known as Knowledge Forum, where students assemble their ideas, questions, and approaches, collectively building “views” of the knowledge, building on peers’ ideas, and adding “rise above” notes that synthesize and extend a collection of peers’ ideas. The use of such a persistent and dynamic knowledge base circumvents the typical discourse pattern adopted by teachers in classroom discussion of “Initiation-Reply-Evaluation” (Mehan, 1979) – in which the teacher initiates a question, a student responds, then the teacher evaluates the response. Instead, the growth of an external, visible, and accessible knowledge base allows the teacher new discourse opportunities to foster student agency and articulate their own inquiry progressions (Scardamalia, 2002).

Unlike more “procedural approaches” such as Reciprocal Teaching, KB is a “principle-based approach” (Zhang et al., 2011; Scardamalia & Bereiter, 2010, 2006) with 12 principles that serve as pedagogical guides, technology design properties, and evaluation criteria (paraphrased from Scardamalia, 2002; p. 9-12):

1. *Real ideas, authentic problems*: learners in an effort to understand the world, identify problems and pursue creative work that produces ideas, which become their own entity.
2. *Improvable ideas*: all ideas are treated as improvable, and learners continuously work to improve the quality, coherence, and utility of ideas.
3. *Idea diversity*: a multiplicity of ideas is essential to knowledge advancement. To understand an idea is to understand the ideas that surround it, including those that stand in contrast to it.
4. *Rise above*: learners work with diversity, complexity, and messiness; toward new syntheses that elevate learners to higher planes of understanding.
5. *Epistemic agency*: learners contribute their ideas and negotiate a fit between these and the ideas of others, taking contrasting ideas into consideration. Learners set goals, assess their ideas for coherence, and carry out long-range planning – tasks normally taken on by teachers.
6. *Community knowledge, collective responsibility*: contributions to the collective knowledge from all members of the community are valued. All members share responsibility for the overall advancement of knowledge in the community.
7. *Democratizing knowledge*: All participants are legitimate contributors to the shared goals of the community, and take pride in the community’s knowledge advances. Diversity and divisional differences are assets to the community, and do not lead to have/have-not or innovator/non-innovator separations.
8. *Symmetric knowledge advancement*: Expertise is distributed within and between communities. Knowledge exchange leads to symmetry in knowledge advancement.
9. *Pervasive knowledge building*: knowledge building is not confined to particular occasions or subjects, but pervades mental life and across contexts.
10. *Constructive uses of authoritative sources*: learners access and evaluate authoritative sources of information, not as a final solution to a problem, but as a reference from which to inform their idea refinement.

11. *Knowledge building discourse*: the community engages in discourse to refine and transform the collective knowledge, as they work towards the advancement of knowledge.
12. *Embedded and transformative assessment*: the community engages in its own internal assessment as a natural process of the community's knowledge building discourse, and serves to ensure that the community's work will exceed the expectations of external assessors.

A substantial body of classroom-based research has investigated the KB approach (Wise et al., 2012; Laferrière et al., 2010; Hmelo-Silver & Barrows, 2008; Hmelo-Silver & Bromme, 2007; Hewitt & Peters, 2006; Messina & Reeve, 2006; Hmelo-Silver, 2003; Stahl, 2000; Scardamalia, Bereiter, Hewitt, & Webb, 1996; Scardamalia, Bereiter, & Lamon, 1994). Recent improvements to the KB environment, and the growth of an international community of KB scholars has led to an expanding research literature that continues to investigate and extend the theoretical and pedagogical principles (Cacciamani, 2010; Chen et al, 2011, 2012a, 2012b; Chen, Scardamalia, & Resendes, 2012; Oshima, Oshima, & Matsuzawa, 2012; van Aalst & Truong, 2011; Zhang & Sun, 2011; Zhang, Scardamalia, Reeve, & Messina, 2009; Teplovs, 2008; Hakkarainen, 2004, 2003a, 2003b).

While KB has been applied successfully in classroom studies, researchers acknowledge that the principles are quite abstract and lack implementation strategies, potentially impeding wide-scale uptake of the knowledge building methodology. It can take several years for a teacher to establish an epistemic climate of knowledge building (Scardamalia, 2002), and some recent efforts to apply KB within secondary or higher education, have met with limited success where researchers implemented clear procedures (van Aalst, 2009; Chan & van Aalst, 2004). While some teachers find a principle-based approach to be empowering, it has been recognized that, on their own, the KB principles could be seen by practitioners as “too abstract to be very helpful” (Scardamalia and Bereiter, 2006; p. 108).

### **Fostering Communities of Learners (FCL)**

Another example of the knowledge community approach is seen in the “Fostering Communities of Learners” (FCL) project (Brown & Campione, 1994; 1996). While shorter-lived than KB (i.e., in terms of uptake and development within the research literature), the FCL project remains an important exemplar of knowledge communities, and contrasts with KB in its emphasis of carefully sequenced student activities. FCL also includes explicit epistemic instruction, encouraging students to think of themselves as a scientific community, and to perform inquiries and exchanges as they occur within a scientific community: conducting investigations, sharing findings, incorporating evidence from others, and distributing expertise. “A key idea in the learning-communities approach is to advance the collective knowledge of the community” (Collins, 2006; p. 55), whereby individual students learn within a personally relevant social and conceptual context (Collins, 2006).

The FCL approach was designed around principles of learner agency, reflection on metacognition and knowledge, collaboration of distributed expertise, a culture of open learning and exchange, and deep conceptual content (Brown, 1997; Bruner, 1996). Learning in such communities is student-centered, self-reflective, and social (Brown & Campione, 1996; Brown, 1994). Principles of the learning community approach emphasize learner and ZPD diversity, as each student pursues his or her own trajectory within and beyond the classroom, towards increasingly higher competency levels. This learning process is fostered through shared discourse, where multiple voices of interdependent learners openly share their distributed expertise – as would occur in a community of research practice (Brown & Campione, 1996). In FCL, content must have conceptual substance, be developmentally appropriate, and be personally relevant to students. Assessment practices must be authentic, transparent, and aligned with the curriculum (Brown, 1994).

Student roles, collaborative structures, and interaction patterns are defined through successive inquiry phases as specified by the FCL model, including the use of jigsaw grouping (Aronson, 1978), to help distribute expertise. FCL was implemented in the form of multi-week science inquiry units culminating in group presentations of findings to the wider classroom learning community. Brown and her colleagues used this approach with 2<sup>nd</sup> grade science students for 3 iterations of a 10-week FCL environmental science unit that culminated with a “design an animal of the future” task (Brown, 1997). Children in the first iteration provided design features for such an animal, but the features were disconnected from each other and from any common environmental factors. After a year-long intervention, children in the second replication managed to make some animal design connections related to food chain and predator-prey factors. Children in the third replication designed the habitats first, then a corresponding animal of the future – greatly improving connections between habitat and animal design.

Reflection and discussion are crucial in an FCL classroom, and the teacher is instrumental in guiding productive discourse. Teachers model thinking and reflection, prompt students to justify and support their claims, challenge student thinking, encourage students to summarize what they know and what they still have yet to learn, and facilitate whole-class goal-setting for successive inquiry stages. Furthermore, teachers lead benchmark lessons at pivotal points throughout the inquiry process – when they deem their class is ready to progress to a new level of abstraction in the inquiry (Brown, 1997). Engle (2006) followed two 5<sup>th</sup> grade science classes participating in a 4-month FCL endangered species unit. She suggested that a fruitful approach to explaining how and why transfer of learning occurs is to analyze the content and the framing of learning contexts by time and by participation, then compare the framing of learning situations as ongoing activities and as “bounded events”.

Very few researchers have replicated or extended the FCL approach, as reviewed by Shulman & Sherin (2004). Mintrop (2004) studied teachers' planning and implementation of two FCL social studies units. He found that while the pragmatism of social studies and its multiple perspectives made this domain conducive to constructivist and jigsaw approaches, the piecemeal nature of multiple disciplinary fragments led to weak conceptual synthesis in the curriculum units and a difficult search for 'big ideas'. Rico and Shulman (2004) explored teachers' development and implementation of science FCL units (i.e. 'invertebrates' and 'circulatory system'), and found a loss of emphasis on big ideas, a lack of inter- and intra-group interdependence, little meaningful peer discussion, and no sharing of expertise in teachers' FCL implementations; despite teachers' robust understanding of science content and FCL. Central to this discrepancy was a conflict between teachers' belief of what science education should be, and their theoretical understanding of FCL. Whitcomb (2004) examined three middle and secondary school teachers' design and implementation of FCL in their English classrooms and found that traditional models of literature instruction hinder FCL implementation, whereas simplification of FCL combined with gradual experimentation leads to increasing approximations of FCL integrity. Sherin, Mendez, and Louis (2004) followed a middle school math teacher's 2-year adoption of FCL, and found that teaching math through FCL necessitates the teacher to make 3 shifts: (1) the learning of both math concepts and processes should be emphasized, (2) the teacher's role includes developing learning activities, eliciting student comments, and pursuing these during whole-class discussion, and (3) a discourse community could be instrumental to FCL implementation in a math classroom.

Shulman & Sherin (2004) point out that the success of FCL depends on teachers' and students' understanding of the theory at the heart of FCL pedagogy, and have identified 4 challenges of FCL implementation: (1) teachers need to identify the big ideas in their curriculum

and plan instruction around these, (2) big ideas must be ‘jigsawable’ so that students become interdependent in their collaborative investigations, (3) different domain disciplines have their own teaching traditions and curricular habits, which may impact a teacher’s pedagogical understanding of FCL, and (4) disciplinary differences may result in implementation differences of FCL protocols (e.g., learning community establishment, “benchmark lessons”, jigsaw group work, “cross-talk”, group inquiry and design).

### **Knowledge Community & Inquiry (KCI)**

To help make the knowledge community approach more accessible to science teachers, Slotta and his colleagues have added a layer of scripted inquiry (Fischer et al., 2013; Raes et al., 2012) to advance a pedagogical model known as Knowledge Community and Inquiry (KCI - see Slotta, 2014; Slotta, Tissenbaum, & Lui, 2013; Slotta & Najafi, 2012). KCI retains the emphasis on collective epistemology (i.e. community identity and orientation) and knowledge construction, and blends a set of principles with an emphasis on the design of carefully sequenced student activities, inspired by FCL, including structured collaboration scripts for distributing expertise (i.e. jigsaw designs - Aronson, 1978), teacher-led benchmark lessons at pivotal points in the inquiry, and defined collaborative structures (Brown, 1997; Brown & Campione, 1996, 1994; Bruner, 1996).

KCI curriculum typically spans multiple weeks or months, during which time students are supported as they come to identify and work as a knowledge community (Slotta & Najafi, 2010), traversing between individual, small group, and community “planes of learning” (Stahl, 2013). Students collaborate in a technology-enhanced learning environment to build a collective knowledge base which becomes a resource for subsequent scaffolded inquiry activities, often incorporating a jigsaw (Aronson, 1978) element (Slotta & Najafi, 2012). These inquiry activities

target specific science learning goals (Peters & Slotta, 2010). Thus, KCI emphasizes a procedural approach, more closely resembling FCL than KB, but still represents a knowledge community approach, as it also emphasizes collective epistemology, negotiated values or themes, and shared discourse patterns.

KCI curriculum is developed through a sustained process of co-design (Roschelle & Penuel, 2006) between researchers, teachers, and technologists, resulting in a carefully designed, technology-supported pedagogical “script” that specifies curricular flow, where students may be placed in certain groups or assigned certain materials or activity conditions depending on emergent (i.e. “real time”) student contributions, or mediated by teachers’ spontaneous decisions. For this reason, KCI scripts are described as being “unbound” – meaning that activities and sequences are only partially pre-determined, and are left intentionally ill-defined such that they depend on the nature of student-contributed ideas, as well as emergent patterns of aggregate representation and discourse that occurs during the curriculum enactment (Slotta, 2014).

Four principles guide the design of KCI curriculum (Slotta, 2013; Acosta & Slotta, 2013; Slotta et al., 2013):

1. Students work collectively as a knowledge community to produce a knowledge base that serves as a resource for ongoing inquiry within a specific science domain.
2. The knowledge base is accessible for use as a resource for student inquiry, as well as for editing and improvement by all members.
3. Collaborative Inquiry activities are designed that ensure the coverage of targeted science learning goals, including assessable outcomes.
4. The teacher plays a specific role (i.e. “expert collaborator or mentor”) defined within the inquiry script, but also a general orchestration role, scaffolded by the technology environment.

A persistent design challenge is how to “create a sense of autonomy, creativity and inquiry, without ‘overscripting’” (Slotta, in Fischer et al., 2013; p. 570). Students engage in the loosely scripted inquiry activities individually; or in groups that may be self-selected according to topics that arise from their inquiry, or that are defined at the time of script design, or that are determined by the teacher based on student-generated ideas.

Early KCI research explored pedagogical and curricular designs that ensured the community’s inquiry progression, using a Wiki environment to give structure to the community’s knowledge construction. For example, the community could define the main wiki categories and page headers, proceed to populate those pages, and then to use the resulting populated wiki as a resource for scaffolded inquiry (Slotta & Peters, 2008). The first study to provide empirical support for the KCI model employed grade 10 biology students in co-authoring wiki pages about human disease systems, then applying the resulting substantive “disease wiki” to solve peer-created medical case studies (Peters, 2011). A second iteration emphasized collaborative processes as students created a detailed wiki about Canada’s biodiversity (Peters & Slotta, 2010). In another KCI study, grade 9 science students co-constructed a wiki about climate change effects in Canada and remediation plans, comprising 16 climate change issues each indexed to four primary content areas (carbon sinks and sources, energy circulation in the atmosphere and oceans, greenhouse effect, and scientific models). Students then employed this voluminous wiki to inform their proposal of remediation plans that targeted the climate change issues (Najafi, 2012; Zhao et al., 2011).

In more recent KCI research, the CSCL environment is no longer restricted to simply supporting knowledge construction, but now includes carefully designed “emergent representations” of the collective knowledge base which actively guide the community’s

discourse and inquiry progression. Moreover, students are engaged in many different forms of computer-supported inquiry – including note-taking, the manipulation of simulations, problem-solving, tagging and voting, and other forms of scaffolded inquiry. All student interactions are facilitated by a “smart classroom” infrastructure called Scalable Architecture for Interactive Learning (SAIL - Slotta et al., 2013) and pedagogical scaffolds that coordinate inquiry activities through distributed technologies (e.g., tablets, laptops, interactive whiteboards) to script the community’s inquiry progression, supporting students’ organization and use of the community’s ideas.

Recent research on KCI in smart classrooms includes the EvoRoom (Lui & Slotta, 2013), where students work as a whole class to investigate a Sumatran rainforest that is rendered as an immersive room-sized simulation in which their inquiry is embedded, and PLACE.web (Tissenbaum & Slotta, in press), where high school students contribute their own video examples of physics in everyday life, to create a dynamic knowledge base that guides a succession of inquiry activities. These projects feature a role for SAIL infrastructure, including intelligent agents for data mining of student contributions to support real-time reactions, aggregate representations of collective knowledge, and ambient displays of collective inquiry progress.

These recent KCI projects have also included a growing commitment of KCI curriculum to community-constructed narrative and a role for whole-class (i.e., teacher-guided) discourse in determining the progression of inquiry. Bruner (1991) would view the emergent knowledge base as a cultural means by which to influence the community’s construction of narrative, which in turn influences how community members organize their inquiry experiences and thoughts. Indeed, the role of epistemic cognition has been explored through the mapping of the KCI model’s epistemic commitments onto the enacted curriculum (Acosta & Slotta, 2013; Acosta,

2013). These recent developments bring new possibilities for an expanded range of inquiry designs and interaction patterns (Slotta et al., 2013), and the need to develop technology environments with an emphasis on promoting discourse-driven inquiry.

The knowledge community perspective, particularly KCI, offers a theoretical and methodological foundation for the present research. In addition, the teachers who are participants in my study are also veterans of Knowledge Building, which has provided them with excellent grounding in the pedagogical and epistemic commitments of the knowledge community approach. Their expertise in guiding discourse and inquiry progression within their own classrooms will greatly contribute to the present investigations of how the Common Knowledge technology can support such discourse.

### **Scripting and Orchestration for Knowledge Communities**

Knowledge community approaches rely on the teacher to cultivate a collaborative learning environment, and to coordinate the dynamic interactions between students, peers, and resources. One means of supporting learners to engage in collaboration processes is through the use of collaboration scripts (Fischer et al., 2012; Weinberger et al., 2010). The “script” (akin to a theatrical script, although not to the detailed level of specific utterances) is designed by researchers or educators to specify the participants’ roles and goals, the allocation of materials, and the coordination of student grouping and learning activities (Dillenbourg & Jermann, 2007; Kollar, Fischer, & Slotta, 2007; Kolodner, 2007). Scripts vary in their degree of specificity, and it has been noted that while some level of “coercion” (e.g., of student assignment to groups, or temporal sequencing) may be helpful for achieving targeted progressions, too much may contradict the spirit of collaborative learning and impede student motivation (Dillenbourg, 2002). Scardamalia and Bereiter (2003) caution against overly prescriptive knowledge building

environment designs, and have proposed “procedural facilitation” as an alternative that provides essential learning supports while minimizing coercion of activity or condition (Scardamalia & Bereiter, 1985).

Script enactment has been referred to as a process of “orchestration” (Dillenbourg & Jermann, 2007; Kollar et al., 2007) – the real-time coordination of student activity, classroom materials, technology, and utilization of classroom space (Slotta et al., 2013). Dillenbourg recently defined orchestration as “how a teacher manages, in real time, multi-layered activities in a multi-constraints context” (Dillenbourg et al., 2012; p. 1).

The scripting and orchestration of collective inquiry could be approached, albeit at the risk of “overscripting,” through the use of scaffolding technology environments that integrate collaboration and inquiry scripts, and planned opportunities for collaborative discourse (Kolodner, 2007). Such scaffolds could also serve to support the community’s external knowledge representations and knowledge convergence (Fischer & Mandl, 2005), as well as a teacher’s orchestration of the script (i.e. the “run-time script” - Tchounikine, 2013). Such orchestration technologies should ideally serve to minimize teachers’ “orchestration load” (Dillenbourg, 2012), enabling the community to manage ideas as they emerge and to manage the community’s inquiry process.

In a KCI curricular script, student-student, teacher-student, student-technology, and teacher-technology interactions are specified to a level of detail that assures progression within the inquiry design, but still allows student ideas to emerge and dictate the specific progressions of inquiry and discourse on any given class day. For example, the script might specify that the teacher would hold an opening discussion to encourage students to share their ideas about biodiversity, then subsequently guide students to initial observations about a simulation in their

classroom technology environment, encouraging spontaneous observations until finally reconvening the class to discuss patterns, conflicts, or gaps in the observational data as seen in a large aggregate display (Cober, McCann, Moher, & Slotta, 2013). The classroom space and materials within it (e.g., walls, furniture) play a coordinating role within the script (Slotta et al., 2013; Slotta, 2010), particularly in presenting larger, aggregate representations of community knowledge on ambient displays (e.g., using an interactive whiteboard that the teacher can occasionally reference and guide further inquiry trajectories). Two common topics of research within KCI are concerned with: (1) how to dynamically represent the community's individual and collective knowledge so that it is accessible as a resource for discourse and inquiry, and (2) how to orchestrate the “unbound” pedagogical script such that it can respond to emerging student contributions (Slotta et al., 2013).

### **The Role of Discourse in a Knowledge Community Approach**

Language has been shown to be a central mediator of thinking and learning within a knowledge community (Hicks, 1995; Wertsch & Smolka, 1994), as communication with peers and teachers generates new meaning or insight about next steps for inquiry (Sfard, 2007). Learning through discourse can be viewed as a social process of meaning construction (Vygotsky, 1962). Some research has explored the role of argumentation discourse in fostering scientific thinking, where learners are presented with warranted claims and refine their arguments in light of developing evidence (Bell, 2000; Kuhn, 1993). However, such approaches have been criticized for removing learners as producers of scientific knowledge, and placing authority (i.e., of argumentation strategies and content) on teachers (Lemke, 1990) and textbooks (Sandoval & Reiser, 2004).

Others have focused on theory-building and explanation, in an effort to move discourse in the classroom closer to the epistemic practices of scientists (Bereiter & Scardamalia, 2012; Sandoval & Reiser, 2004; Nickerson, 1985). This work has drawn on ideas of “inference to the best explanation” (i.e. determining which hypotheses best explains the evidence - Lipton & Hobbs, 1991), explanatory coherence (i.e. determining which hypotheses allow a coherent explanation of the phenomena - Thagard, 2006), and cognitive apprenticeship (i.e. participating in expert-like cognitive processes in real-world contexts - Collins, Brown, & Holum, 1991).

Researchers of the knowledge community approach generally recognize the importance of dialogue. Bereiter and Scardamalia (2008) define five levels of classroom dialogue, varying in their levels of structure and teacher directedness: recitation, teacher-mediated dialogue, teacher-managed argument or debate, teacher-monitored small group discussion, and authentic problem-solving peer discourse. They argue that Reciprocal Teaching (Palinscar & Brown, 1984) was conceived as a transitional discourse structure to help students progress from teacher-mediated dialogue to independent small group discussion, with a gradual fading of teacher direction and structure.

Mehan (1979) studied teacher-student interactions to understand the functions of language in the classroom and identified a common interaction sequence: a teacher’s initiating speech act, followed by a student’s response statement, and closing with the teacher’s evaluative statement of the student’s response, known as IRE (initiation, reply, evaluate) or IRF (initiation, reply, follow-up), and more recently referred to as “triadic dialogue” (Lemke, 1990). Extended patterns of discourse consists of iterated IRF sequences which continue until the called-for reply fulfills “symmetry” between initiation and reply acts (Mehan, 1979).

Nassaji and Wells (2000) demonstrated that the teacher's choice of initiating discussions and follow-up questions influences the efficacy of triadic dialogue as a means of knowledge co-construction. They observed written and spoken discourse in inquiry-oriented classrooms of nine elementary and middle school teachers over six years, and noticed three types of initiating questions: (1) probing for known information, (2) eliciting personal perspectives, and (3) prompting social negotiation through open-ended discussion. Six categories of follow-up moves were found: evaluation, justification, comment, clarification, action, and meta-talk. The most substantive student responses were found to result from initiating questions that elicited negotiation, debate, or multiple perspectives. Evaluative follow-up comments were seen to suppress extended student participation, except when they followed a negotiating question. Initiating questions that elicited known information could develop into productive dialogue if the teacher's follow-up involved requests for justification, connections, or counter-arguments, and students were free to self-select discussion participation. Thus, IRF teacher-student interaction patterns have been found to promote knowledge co-construction discourse in the classroom.

Teachers and students engaged in classroom discourse draw simultaneously on their content knowledge as well as on two forms of procedural knowledge: academic task structure (ATS) and social participation structure (SPS - Erickson, 1982). O'Connor and Michaels (1996) propose the construct of "participant frameworks" as moment-by-moment constructions of all members' participation status relative to any utterance. This allowed the analysis of "revoicing" – the oral or written re-phrasing of a student's contribution by another participant, often the teacher. Analysis of revoicing allowed the researchers to describe how teachers orchestrate group lessons through language socialization into intellectual practices, by positioning students in relation to each other and aligning them with the academic content at hand.

Through revoicing sequences, a teacher may credit students for their contributions, clarify them, and then “animate” or cast students into intellectual roles; thereby socializing them as legitimate participants of intellectual practices. Teachers’ revoicing may also serve to “lamine” or fuse students’ phrasing or informational content amongst various students’ contributions, connecting multiple ideas and building coherence. The process of revoicing student comments can serve to advance the discussion by (1) using student contributions to introduce new ideas or terminology, (2) reframing student contributions to steer the discussion in another direction, (3) positioning a student in relation to the argument by attributing his or her comment to a stance, or (4) creating alignments and oppositions within an argument – thereby positioning students in relation to their peers (O’Connor & Michaels, 1996). “Revoicing” thus offers a means for teachers to scaffold classroom discourse, foster idea growth, reinforcing collective epistemology, and guiding inquiry progression.

When a teacher revoices a student’s comment followed by a warranted inference prompt (e.g., using the trailing “so...”), students are provided the opportunity to affirm or deny the teacher’s warranted inference. This contrasts with Mehan’s (1979) IRE sequence where the *teacher evaluates the student’s reply* and the student has no opportunity to negotiate the meaning of his/her contribution. Conversely, a teacher’s revoicing of a student’s contribution inherently implies acceptance of the student’s response, by using it as a basis for warranted inference, and thereby allowing the *student to evaluate the teacher’s inference*. Hence, the revoicing participant framework provided by O’Connor and Michaels (1996) allows “an expanded and more contrapuntal set of voices and participant roles in constructing an idea than does IRE” (O’Connor & Michaels, 1996; p. 97).

One aim of the present study is to identify the kinds of revoicing used by teachers in their facilitation of productive inquiry discourse within a knowledge community approach for upper elementary science. Building on the notions that “thinking is externalized in the form of discussion” (Brown, 1994, p. 7), and that discourse-mediated interactions serve as the mechanisms for development of higher-order thinking (Wertsch & Smolka, 1994; Bakhtin, 1986; Palinscar & Brown, 1984; Vygotsky, 1962), inquiry in the KCI classroom has been described as progressing through discourse (Slotta, 2013; Cober et al., 2013). In particular, KCI gives rise to new forms of interaction (and opportunities for discourse) through its use of persistent, emergent representations of student knowledge (e.g., large aggregate displays that capture the emerging collection of student observations). This is similar to the role played by the persistent discussion thread in online discussions, where the knowledge is externalized and hence available as a referent (Hakkarainen et al., 2013; Hewitt et al., 2013; Zhang & Sun, 2011; Gan et al., 2010; Wise et al., 2009; Scardamalia & Bereiter, 2003). Yet the role of discourse in advancing ideas within a KCI framework of learning has not been studied explicitly, in part because earlier KCI work utilized wikis as a medium for collaborative knowledge construction, and the discourse amongst students and teachers was not captured or analyzed. Thus, the content of specific exchanges is not well understood, nor how those exchanges led to patterns of artifact contribution or inquiry progressions in the knowledge community. This study examines the role of classroom discourse in KCI, to help students to access and make use of their community’s knowledge, advancing their inquiry through the intended progression (i.e., the script).

### **The Role of Technology Environments: Scaffolding Discourse and Collaboration**

The use of technology-mediated, persistent representations of student ideas can support classroom discussions to augment and inform the IRF interaction patterns, allowing for new

patterns to emerge, particularly with regard to the revoicing of student ideas. Technology has long been used to support online discussions (Linn & Hsi, 2000; Peters & Hewitt, 2010) and knowledge building (Scardamalia & Bereiter, 1996, 2003), where it has served an important role in making student ideas visible to peers, allowing for the progress of ideas and persistent representation. This dissertation is exploring how one note-sharing system, Common Knowledge, supports teacher-guided discourse in helping the classroom knowledge community understand its current state of knowledge and collectively progress in inquiry. Through several design iterations that focus on supporting discourse patterns, it is hoped that the Common Knowledge technology environment can be developed in such a way that it lends itself more naturally to productive conversations and the furthering of scientific inquiry.

New advances in CSCL research have yielded technologies that adopt a social constructivist perspective, positioning discourse as a fundamental component of inquiry. Recent technological advances include the development of extensible messaging and presence protocol (XMPP), which allows for real-time instant messaging and co-authorship (e.g., Google Docs). This in turn supports new forms of infrastructure that allow for scaffolds that support collective and individual inquiry (Slotta, 2010; Raes et al., 2012), and a distributed array of interlinked inquiry technologies (Kreitmayer et al., 2012; Slotta, Tissenbaum & Lui, 2013). Mighty Mouse (Booth et al., 2002) enabled learners to view and interact with all virtual desktops of all co-located computers. ConcertChat (Stahl, 2006), as used in the Virtual Math Teams (VMT) project, allows small groups to chat online whilst collaborating on a math problem in an online shared whiteboard space, and reference specific parts of the drawing/solution on the whiteboard in their chat. Group Scribbles (Roschelle et al., 2007) supports multi-learner coordination and idea sharing, as students use digital ink to draw or write on arrangeable virtual sheets of paper via tablet computers.

A variety of projects have tapped into the potential for interlinked technologies to enhance or scaffold discourse for collaborative learning in a face-to-face (F2F) learning environment such as a K-12 classroom. By scaffolding collaboration in “real time” (i.e. as the class session progresses), these technology systems can support knowledge sharing and progression (Kreitmayer et al., 2012), as well as more agile teacher orchestrations (Slotta, 2010). In the Computer Supported Intentional Learning Environments (CSILE) environment, Scardamalia and Bereiter pioneered Knowledge Building discourse technologies. First prototyped in 1983, CSILE has now evolved into Knowledge Forum (KF), which provides a digital space for a wide range of research and practice in the knowledge building pedagogy in K-12 and higher education (Scardamalia, 2004). Within KF, students can access cognitive scaffolds to support their intentional learning, that help to structure their discourse contributions (e.g., “I need to understand”, “This theory cannot explain”).

Innovative asynchronous environments have also emerged, to support distance education or online components of higher education courses. For example, PeppeR (Hewitt et al., 2013) offers innovative structures for online discussion, including a layer of social affordances (e.g., “likes” for promising threads). Other systems have incorporated visual interfaces of student responses, such as a hyperbolic tree-based visual discussion forum – (Marbouti, 2012); Moodle, a modular open source Web-based forum (Dougiamas & Taylor, 2003); and InterLACE, a flexible Web-based forum that includes a persistent whiteboard-like workspace and allows learners to rearrange post-it style note objects in which they have captured their ideas through text, images, screenshots, and sketchings (Coopey et al., 2013). While all of these environments allow members of a classroom or other online community to represent ideas and interact in a social environment, they do not contain built-in scaffolds for discourse progression, and rely instead on the teacher’s intuitive sense of progress and orchestration.

Mazur (Crouch et al., 2007; Mazur, 1996) has popularized an approach known as Peer Instruction using audience response systems (“clickers”) to engage undergraduate physics students in reflecting about challenging conceptual problems first individually (including a clicker “vote”) then in collaboration with a peer, where they negotiate their revised vote. While the clicker technology facilitates low-risk student polling and quick formative assessment, the discourse (i.e. productive reflections and exchange amongst peers) is orchestrated by the teacher without any technological supports.

One approach that has developed procedural supports for discourse is that of CollPad (Nussbaum et al., 2009), which uses handheld touch devices to deliver collaboration “scripts” that facilitate a reciprocal process of problem solving and inquiry across a classroom’s social planes. A ‘collaboration script’ defines how learners interact with one another, and how they approach a specific task. The CollPad script aims to support productive collaboration and problem solving, and uses visualizations to reveal each group’s progress (i.e., within the collaboration script) to the teacher. However, the script still relies on the teacher to monitor the flow of ideas and discussions amongst the student groups, and to respond to incoming solutions. All of these technologies aim to empower student groups to work productively and to share their knowledge artifacts with others, promoting progress in the knowledge community.

Many of the environments described above rely explicitly on classroom discourse, led by the teacher, to ensure such progress. However, such a reliance on the teacher to guide inquiry discourse and activity sequencing can place a heavy cognitive load on the teacher (Baddeley, 1992; van Bruggen et al., 2002; Tchounikine, 2010). For example, teachers would need to monitor, in real-time, the community’s real-time emerging ideas, while simultaneously managing the classroom and engaging seamlessly in multiple small group interactions. The productivity of

inquiry discussion depends largely on the teacher's on-the-fly analysis and facilitation skills. Furthermore, while individual students may discuss ideas with a few peers, it is an ongoing challenge for teachers to help students connect their ideas with peers' contributions, thereby helping them form conceptual connections that leverage the community's wider knowledge assets. Technology environments can help to support a community's discourse in student-driven inquiry. Such environments could include visualizations of the knowledge community's progress, help scaffold collaborative student groupings, and help the teacher make efficient use of time and online resources (Slotta, Tissenbaum & Lui, 2013).

Engle and Conant (2002) offered four design principles for learning environments that foster what they refer to as productive disciplinary engagement (PDE): (1) problematizing content; (2) giving students authority/agency; (3) holding students accountable to others and to disciplinary norms; and (4) providing relevant resources. PDE includes the tracking of disciplinary understandings, and sees learning as both cognitive and social. The PDE principles hold promise both as a means of informing design, and as a framework for which to evaluate technology environments that foster a community's discourse and inquiry.

While technology environments have been designed to help students make progress as a knowledge community, teachers need support in the orchestration of such discourse. Penuel and his colleagues (2012) discuss 3 means by which teachers can orchestrate productive talk: norms, pedagogical patterns, and talk moves. Moderators of online learning are urged to consider elements of voice (e.g., generative guide, conceptual facilitator, reflective guide, mediator), tone (e.g., nurturing, curious, analytical), and critical thinking strategy (i.e. to sharpen focus, or to dig deeper) when creating a forum posting (Collison et al., 2000). These are examples of discourse

structures or guidelines for productive oral and online discourse, which may include the use of IRE, and revoicing techniques.

Though productive discursive activity can be guided (Engle & Conant, 2002; Penuel et al., 2012; Sfard, 2007), it is important to remember that classroom discourse may also be spontaneous, itinerant, and heterogenous (Lemke, 2009). Knowledge Forum and other persistent, asynchronous environments allow for the development of ideas with emergent structure and opportunistic connections. Recently, Wise and her colleagues (e.g., Wise et al., 2012) have offered new analytic techniques for asynchronous discourse within online knowledge communities, which consider the progress of individuals and groups in terms of ideas and inquiry processes.

The research described here is making progress in helping teachers to facilitate a knowledge community's collective inquiry through intentionally designed technology environments and guided discursive activity. The role of the teacher is of paramount importance in of these environments, which can present a high cognitive or orchestrational load. The next section presents the specific research questions that have guided my design and evaluation of Common Knowledge through three iterations, which are concerned with supporting teacher orchestration with new technology affordances that make inquiry progress more visible, and make it easier for teachers to utilize revoicing and other discourse techniques that incorporate student ideas – all while still allowing some flexibility and spontaneity.

## **Research Questions**

Research of the interaction between oral and written discourse has found that participation in collaborative oral argumentation and reasoning promotes individual written

reasoning (Reznitskaya et al., 2001), that internal scripts influence oral discussions while external scripts influence writing (Kollar et al., 2008), that oral collaborative discussions about written reasoning help individuals to see the limitations or the value of their ideas and rethink their explanations as needed (Mason, 2001), and that the complexity of collaborative and individual argumentation relates directly to learning and should be accompanied by task structures that promote more complex argumentation (Chinn et al., 2000). For the most part, unidirectional interactions between written online contributions and oral classroom discourse have been studied, but little research has addressed the bi-directional integration of the two discursive modes.

While the teacher's role is pivotal in facilitating productive inquiry-oriented discussions within a knowledge community (Brown & Campione, 1994; Engle & Conant, 2002; Scardamalia & Bereiter, 2006; Slotta & Najafi, 2010), little work has addressed technologies designed to help teachers respond in real-time to the barrage of incoming student ideas as a resource through which they can promote deeper understanding and enable the progression of inquiry within the community. Kollar and his colleagues (Kollar et al., 2008; Kollar & Fischer, 2013) have argued that when a teacher is confronted with a daunting amount of complex, heterarchical information generated by students within a CSCL environment (e.g., hypothesis formulation, modeling, empirical evidence, argumentation, and/or questions), he or she may benefit from a "collaboration script" that embodies the targeted progression of inquiry activities across a classroom's social and temporal planes. To help realize such a script in the design of a scaffolding technology environment (e.g., Common Knowledge), it is important to consider how the teacher would orchestrate or pace the script, as well as any possible supports for teachers to make extemporaneous "on-the-spot" orchestrational moves (e.g., spontaneous group formations or introducing new inquiry activities based on something that came up during class). One

important design goal for Common Knowledge is to create a technology environment that helps teachers and students as they engage in scripted, but flexible inquiry.

The effective use of technology-mediated representations of student ideas for purposes of collective inquiry relies heavily on teacher orchestration of guided community discourse. Teachers' revoicings have the potential to affirm students' contributions and legitimize their roles in the inquiry, while also serving as a vehicle for teachers to model expert inquiry processes when engaged with representations of students' ideas during knowledge work. This would be consistent with the cognitive apprenticeship approach, where, in the case of collective inquiry within a KCI approach, the teacher – viewed as a co-inquirer by the knowledge community and who has cultivated expert skills in inquiry and knowledge working – mentors the community in their metacognitive development of inquiry skills and knowledge work (i.e. working with ideas). The present research aims to focus on the role of classroom discourse with a KCI curriculum, identifying patterns of student and teacher activity and discussion, examining how knowledge is referenced and applied, and advancing a new technology environment to support the representation and use of knowledge within the classroom community. Specifically, I will develop specific forms of knowledge representation, and technology infrastructure (including real-time messaging and intelligent agents) to support teachers in leading oral discussion that help to advance student inquiry. My research questions are as follows:

1. How do features of the Common Knowledge technology environment support inquiry-oriented discourse and progress within the knowledge community?
2. How can a note-sharing environment such as Common Knowledge be integrated into a sequence of inquiry activities to support progress?

3. What forms of teacher-guided discourse are important to the successful application of community note-sharing environments in elementary classrooms?

The study will pursue a design-based research method (Wang & Hannafin, 2005; Collins et al., 2004; Design-Based Research Collective, 2003), engaging two teachers at a local elementary school help to co-design KCI activities that employ Common Knowledge (CK). Teacher interactions with students and their knowledge products will be studied, including teachers' orchestrational and discourse moves, and the outcomes or consequences of those moves. CK will be informed, evaluated, and improved through three iterations of design and enactment, resulting in: (1) a set of findings that reveal patterns of orchestration and discourse within KCI enactments (2) a viable technology environment that can support further research of KCI and other knowledge community paradigms, and (3) a set of design principles for inquiry scripts that employ CK or similar technologies.

## Chapter 3: Methodology

This dissertation study is part of a large multi-year funded research project called Embedded Phenomena and Inquiry Communities (EPIC - see Moher & Slotta, 2012) conducted by researchers and technologists from the University of Toronto and the University of Illinois at Chicago (UIC), in collaboration with teachers and administrators at the Dr. Eric Jackman Institute of Child Study in Toronto. EPIC is funded by grants from the US National Science Foundation and the Canadian Social Sciences and Humanities Research Council. The goal of EPIC is to investigate a technological innovation called “Embedded Phenomena” (Moher, 2006) where a digital simulation is embedded (i.e., distributed, in the form of computer displays or other technology) in the walls, floor or furniture of the classroom environment, which students must investigate collectively, to advance their understanding of underlying scientific concepts. Embedded Phenomena (EP) have been developed in topics of biodiversity, planetary orbits, and aquifer hydrodynamics, and the EPIC project was funded to investigate a knowledge community approach to supporting student and teacher inquiry about EP. In each year of the EPIC research the Common Knowledge (CK) environment has been designed and developed as one component of the broader technology and curriculum materials, with a distinct role to be played by the CK note-sharing system, in relation to an overarching curriculum and inquiry design.

All curriculum and technology environments were designed collaboratively in partnership with researchers and technology developers from the two universities, as well as two teachers and one administrator from our partner elementary school. The first iteration of CK was integrated with another tablet-based application to support the HelioRoom EP, implemented as a pilot study in May 2011, for a grade 5/6 single 90-minute astronomy activity (Fong, Cober, Madeira, & Slotta, 2012). The second iteration of CK was integrated within the technology

environment for the WallCology EP, enacted in October through December 2011 as part of 9-week grade 5/6 biodiversity unit. Building on analyses of the WallCology activity (Fong, Cober, Madeira, & Messina, 2013; Fong, Pascual-Leone, & Slotta, 2012), the third iteration of CK was a major re-design: a standalone web application enacted in March through May, 2013, to support and guide a 9-week grade 5/6 astronomy inquiry unit (Fong et al., 2014). Many design meetings were held with teachers throughout this time period, to design curriculum sequences, critique technology features, and review any classroom runs in progress. At the end of each curriculum run, a debriefing interview was held with the teachers to capture their immediate evaluations of the EPIC materials, including CK. The sections below present the details of the participants, materials and procedures employed, beginning with a short review of design-based research.

### **Design-Based Research**

Design-based research (DBR) is an empirical method for designing and investigating learning innovations in authentic classroom contexts, to understand how, when, and why they work in practice, with an eye toward the improvement of theory and practice (Wang & Hannafin, 2005; Bell, 2004; Collins et al., 2004; Hoadley, 2004; Cobb et al., 2003; Design-Based Research Collective, 2003; Sandoval & Bell, 2004). The objective of DBR is to connect educational research with contexts of practice, emphasizing iterative cycles of design, enactment, analysis, and redesign (Cobb et al., 2003; DBRC, 2003) to systematically refine the innovation and produce extensible design principles (Amiel & Reeves, 2008). Sustained collaboration and emphasis on supporting learning requires researchers to cultivate ongoing relationships with practitioners and to embed their theoretical principles deeply within the “ecology of learning” (Cobb et al., 2003).

Design-based research should document the designs, rationale, and enactment outcomes (Hoadley, 2004), as the methodology responds to emergent theoretical ideas, which in turn improves designs (Sandoval & Bell, 2004). Multiple sources and kinds of data are typically triangulated to investigate the intended and unintended enactment outcomes (DBRC, 2003). Bell (2004) argues for the conceptualization of DBR as a methodological orientation with a set of modes that can be applied to various theoretical perspectives and research traditions. Bannan-Ritland (2003) proposes an integrative learning design (ILD) mode of DBR that merges design and research processes. Wang and Hannafin (2005) have identified nine principles of DBR with technology-enhanced learning environments:

1. Support design with research from the start.
2. Conduct research in real-world settings.
3. Set goals for theory development, and develop a plan.
4. Collaborate closely with participants.
5. Implement research methods systematically and purposefully.
6. Analyze data immediately, continuously, and retrospectively.
7. Refine designs continuously.
8. Document contextual influences with design principles (i.e. design principles should be context-sensitive).
9. Validate generalizability of the design.

While an important strength of DBR is its ability to respond to emergent contextual changes (DBRC, 2003), there is a tension between researchers' need for experimental control and the need to situate the designed innovation meaningfully within often complex settings (e.g., a classroom). This often necessitates just-in-time modifications of the intervention to "make it

work” (Sandoval & Bell, 2004), and corresponding adjustments to the empirical argument or analysis.

### **Co-design**

In the present design-based study, all curriculum activities, materials, and technology were developed through the process of “co-design” where researchers, teachers, and technologists collaborated in the full spectrum of research activities, from problem definition, to conceptualization and development of materials and technology environments, to enactment and review of procedures (Sanders & Stappers, 2008). Co-design engages researchers, teachers, and developers in a “highly-facilitated, team-based, role-defined process ...to design an education innovation, realize the design in one or more prototypes, and evaluate each prototype’s significance for addressing a concrete educational need” (Roschelle & Penuel, 2006; p. 606). Roschelle and Penuel (2006) have identified seven characteristics of the co-design method, paraphrased here as suggestions for researchers:

1. Address a tangible innovation challenge.
2. Take stock of current practice and classroom contexts.
3. Maintain a flexible target; gather teacher input through iterations of rapid prototyping.
4. Create a bootstrapping (shared experience) event or process to catalyze the team’s work.
5. Time co-design to fit the school cycle.
6. Maintain strong facilitation and well-defined roles.
7. Central accountability for co-designed product quality usually rests with the Principal Investigator

Tensions can arise within a co-design project, as teachers and researchers may define success differently, focusing on students’ needs or experience, whereas researchers focus more

on fidelity to a theoretical model or empirical design (Shrader et al., 2001; Reiser et al., 2000; Brown & Edelson, 1998). Moreover, technology developers may have different ideas from teachers or researchers about project goals, materials design, and procedure (Bowers & Pycock, 1994). Co-design is a time-intensive process, with potentially conflicting input and expectations from different participants (Rheinfrank et al., 1992). Despite or because of the need to accommodate diverse stakeholder positions, the co-design method can achieve teacher buy-in, as their continuous engagement ensures their comprehension of the surface and deep structure of all aspects of the research (Peters & Slotta, 2010).

## Participants

All three iterations of CK were co-designed with 2 elementary teachers (pseudonyms “Brad” and “Jen”) and a vice-principal of an elementary laboratory school located in a large multicultural Canadian city. The school has a traditional focus on inquiry learning, and all three educators from the school have experience and deep orientation toward a Knowledge Building pedagogy. At the time that we started our collaboration (Spring, 2011), Brad had been teaching for 6 years and Jen for 3 years. Both teachers enacted all 3 iterations of CK with their grade 5/6 classes (see Table 1).

Table 1  
*Summary of Participation in 3 Classroom Enactments of Common Knowledge Iterations*

<b>Common Knowledge (CK) Enactment</b>	<b>Brad’s Class</b>	<b>Jen’s Class</b>
Iteration 1: May 2011 <ul style="list-style-type: none"> <li>• 1 session</li> <li>• CK integrated with HeliRoom tablet application</li> </ul>	Grade 6 students (n = 12)	Grade 6 students (n = 11)
Iteration 2: October - December 2011 <ul style="list-style-type: none"> <li>• 9 weeks</li> <li>• CK integrated with WallCology tablet application</li> </ul>	Grade 5/6 students (n = 23)	Grade 5/6 students (n = 23)
Iteration 3: March - May 2013 <ul style="list-style-type: none"> <li>• 9 weeks</li> <li>• CK standalone application</li> </ul>	Grade 5/6 students (n = 23)	Grade 5/6 students (n = 23)

## **Informed Consent Process**

As previously mentioned, this study was part of the multi-year funded EPIC project, and as such, falls within the realm of the EPIC project's ethics protocol. In the fall of each year of the EPIC project, a detailed information letter (Appendix A) is sent to all students of our two classroom teachers, and a similar information letter (Appendix B) is sent to students' parents or legal guardians. The letter explains the research goals, the teachers' and students' roles in the research, and what students may be asked to do. Students are told they will be asked to volunteer for interviews, and that any volunteers will need parental consent to participate in the interviews. All students are assured their identity will be kept confidential, and that their participation in the study has no bearing on their school marks. Furthermore, students may choose not to participate in the study, and if so, they will still take part in the classroom activities as part of the regular curriculum, but their data will be disregarded in any analysis. To indicate consent for their child to be video recorded during the study and to be interviewed should they volunteer, parents/guardians are asked to complete an "Interview and Video Consent Form" (Appendix C). Any students who do not return a signed consent form are not video recorded. Letters of consent have also been obtained from school administrators and our co-design teachers (Appendix D).

## **Materials and Procedure**

Over the three years of the EPIC research, many forms of technology-enhanced materials and learning environments have been developed to support students and teachers. These include the Embedded Phenomena (EP) themselves, which appear on the classroom walls (via computer displays affixed to each classroom wall) as if "portals" or windows into the simulation. In the HelioRoom EP (described below, Iteration 1 section), the display portals showed colorful discs circling around the classroom at various speeds. To support student observations of this

simulation, a specialized tablet computer application where they could indicate which coloured discs had passed which others. At the front of the classroom, the EPs typically included a larger “aggregate view,” to support the teacher in his or her formative discussions with students. The WallCology EP, used in Iteration 2, is more substantive than HelioRoom, including several distinct phases and requiring several weeks for students to fully investigate the simulated ecology. Hence in iteration 2, there were several distinct software applications written to support those inquiry phases, with corresponding variants for the interactive whiteboard (IWB), which was referred to as the “Common Board.”

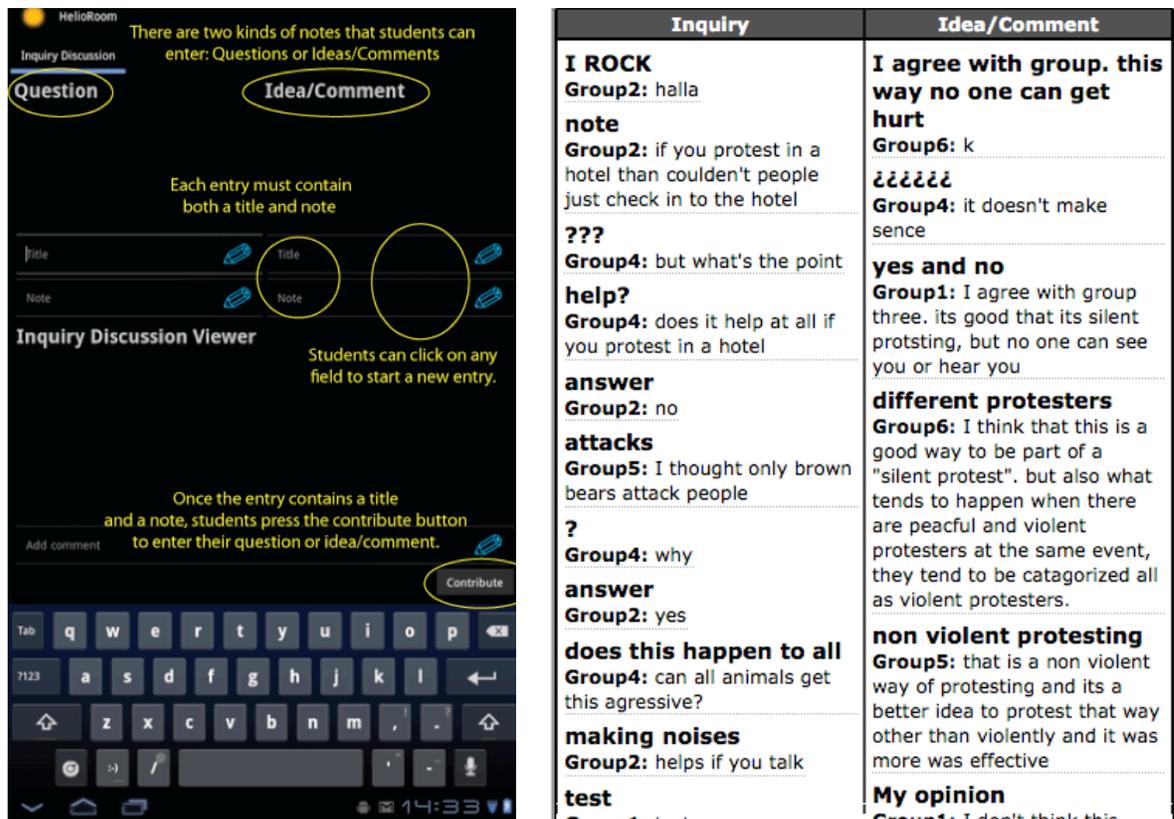
In iterations 1 and 2, CK was integrated into the other EPIC technologies, appearing as a separate tab on students’ tablets and on the IWB. In conceptualizing all EPIC technologies, we developed a description of our expected interactions (i.e., taking notes, exchanging with peers, etc.) into the design of the curriculum activity sequences, or “script”, with all designs striving to support KCI, and responding to teacher values and input. Hence, the technology environment was not designed in isolation from the pedagogical design, but rather in close correspondence with the designed or anticipated curricular script. Tools were generally not developed as “step-by-step” scaffolds (i.e., where students simply click from one step to another) but rather as more open-ended observation forms that would support a range of different interests and modalities of investigation. CK was designed in a similar fashion, as a note-sharing environment that would support students in various phases of their EPIC inquiry. For iteration 3, CK was much more autonomous, as there as only a small EP treatment (HelioRoom, which required only one classroom session). Iteration 3 included several large steps forward, based on outcomes from the previous iterations, where CK would now scaffold the teacher explicitly in using the existing notes to move inquiry forward through a designed sequence.

The design process was thus a high priority in our method, and required months of intensive meetings, discussions with teachers, and then development cycles with technology partners. The sections below present the materials and environments for each iteration of CK, although it must be pointed out that these were done in temporal sequence. Iteration 3 of CK was not even conceived until Iteration 2 had been completed. Moreover, as in any design-based research, the materials and environments in this work should be considered one of the project *outcomes*, as much as they are also part of the method. Hence, chapters 4 and 5 present the designs of all CK versions in greater detail, as outcomes of the study that are linked to the analysis of their enactment. Since these technology environments are also a major part of the methodology (i.e., supporting student inquiry and discourse in the classroom), they will also be reviewed briefly in the following sections of this chapter.

### **CK Pilot Study: News Discussion**

The first version of CK took the form of a short (one class period) pilot study that served to confirm our technology architecture and explore some of the discourse patterns that might be expected. We fit CK into the “Daily News” discussion (held most days in our partner classrooms), as a context for as a pilot test of Common Knowledge, and a basic technological orientation for participants. This version of Common Knowledge provided a very basic interface for students to input “notes” from their tablet computers, with those notes showing up synchronously on the Interactive White Board (IWB) at the front of the room. We found a natural fit for this iteration within the students’ regular “Daily News” Discussion, which the teacher had typically led as an oral discussion. Each pair of students was given a handheld tablet to input either a “Question” or an “Idea/Comment” note (see Figure 2, left). Notes dynamically

appeared on the classroom IWB on a 2-column aggregate table, with “Inquiry” and “Idea/Comment” as column headings (see Figure 2, right).



*Figure 2. Left side: Individual tablet interface from which students could compose and contribute “Question” and “Idea/Comment” notes. However, posted notes could not be read from this interface. Right side: Public IWB display of students’ “Inquiry” (“Question”) and “Idea/Comment” note contributions. Students decided to respond to peers’ notes by including the author name or content in their own note composition (e.g., “I agree with group 3...”).*

Just prior to enactments, teachers were given approximately 20 minutes of refresher training on the CK technology (they had seen mock ups and prototypes during previous design sessions), to assure that they felt comfortable with the technology. Both teachers’ classroom enactments were observed by researchers, technologists, the vice principal, and the teacher of the alternate class section – all of whom participated in a post-enactment focus group immediately following each enactment. Data sources include the researchers’ observation notes, researchers’

debriefing notes, data logs of students' technological activity, student interviews, and educator interviews.

This pilot study had no expectations about an activity sequence or discourse patterns that would transpire during the "Daily News" discussion. Hence, no accompanying script was designed with this pilot version of Common Knowledge. Here, I consider the outcomes of this pilot from two orientations: (1) technical and curricular features, and (2) student-teacher interaction patterns and growth of ideas.

### ***CK Pilot: Technical and Curricular Features***

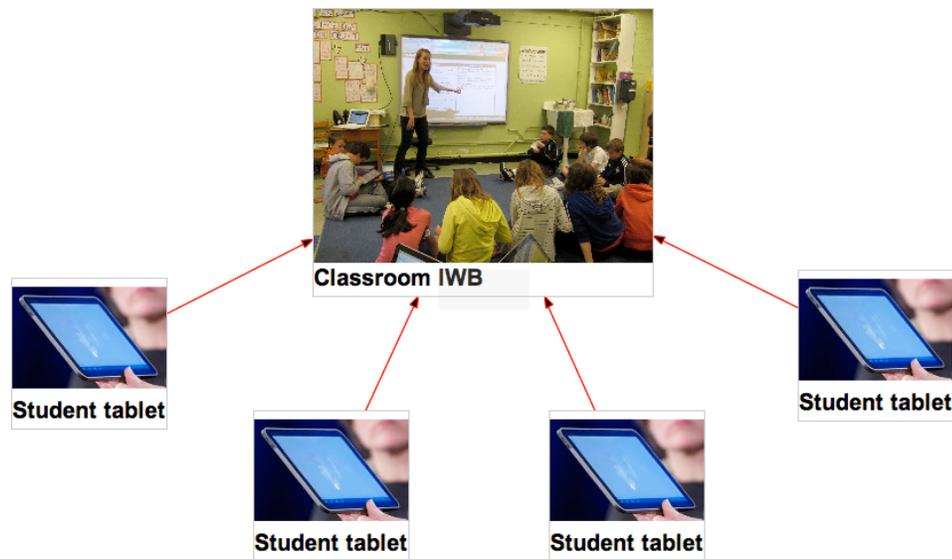
In the focus group following the pilot study, the teachers and vice principal expressed that the students were generally more engaged and made higher quality contributions during the CK-supported "Daily News" discussions than in their regular oral "Daily News" discussions. There was great enthusiasm from the teachers, which was somewhat surprising given that the tablets represented a fairly major intrusion of technology into what had previously been a fairly organic face-to-face discussion. Moreover, it was noted that students who did not normally contribute to oral "Daily News" discussions had actively participated in the CK-supported discussion.

Whereas previous (oral, non-CK) News discussion had typically unfolded in a serial, synchronous stream, CK had enabled all students' ideas to be added efficiently, concurrently, and publicly into the community knowledge base, altering temporal discourse patterns. The IWB instantaneously displayed all note contributions, serving to acknowledge all students' contributions and dynamically display the knowledge community's growing knowledge base

about the News Discussion at hand. Students looked alternatively between the IWB and their tablet to verify that their note had appeared publicly, and to read classmates' notes.

### ***CK Pilot: Student Interaction Patterns and the Growth of Ideas***

Although one goal of this version of CK was to enable students to respond directly to peers' notes from their own tablet, and have all tablet discourse appear on the classroom IWB, our actual functionality only permitted students to contribute notes from their tablets and view their peers' note contributions on the IWB (see Figure 3). Since the students were in close proximity to one another, they could also converse verbally with their peers and teacher.



*Figure 3.* Actual functionality only permitted students to contribute notes from their tablets and view the class' note contributions on the IWB.

The IWB display was the teacher's principal technological gauge of students' collaboration, cognition, and idea growth. Information from the IWB spurred spontaneous coordination of cognitive, pedagogical, and technological dimensions (Fischer & Dillenbourg, 2006). Overall, the discussions were a success. Jen's chosen News topic was about a Mexican

tribe that runs marathons barefoot, to which 11 students working in pairs and a trio contributed 24 notes (an average of 2.18 notes per student). Brad's chosen News topic was the increasing number of black bear attacks on humans, to which students contributed 25 notes (an average of 2.27 notes per student). Interestingly, because Brad had observed Jen's discussion, where he noticed Jen start with an oral discussion, followed by independent student work time in the CK environment, and culminating in a final oral discussion about the publicly displayed CK notes; the two decided together that Brad would actually try out a different approach, where he would continuously have the class alternate between teacher-guided oral discussion focused on the community's publicly displayed ideas, and independent student work time in the CK environment.

Notably, the teachers were quite engaged in reading and responding to student notes as they appeared on the IWB. At several points during the News discussion, both teachers paused their discussions, asking students' attention as they pursued individual notes that they had noticed appear on the board. This was clearly an extension of a discourse move they had developed for the prior, oral versions of News discussion – where they would take the content of a recent student comment, and use it to supply a rhetorical question or reflection, serving the purpose of helping students think more deeply, or consider alternatives. It became clear from the pilot study that such discursive interactions would need to be placed at the center of the design, as these forms of dialog were so valued by teachers, and served such an important role in the general progression of inquiry.

In the debriefing discussion, teachers were enthusiastic about the CK pilot. They expressed confidence that the technology could be used in such a way that it would not “take agency away” from students or teachers. They had many ideas about redesign, which are

summarized in Chapter 4 below, but mainly focused on supporting students in responding to peers, tagging and advancing ideas, and allowing the teacher to work with student ideas on the IWB. All of these inputs were taken into the ensuing design meetings, in preparation for the first real implementation of CK in conjunction with an EP astronomy activity, described in the next section.

### **CK Version 1: HelioRoom**

Iteration 1 of CK responded to the design recommendations of the pilot study, although this aspect of the design is described in Chapter 4, as the design of various iterations is an important research outcome. Here, I describe the basic technology environment and interaction patterns. In Iteration 1, CK was integrated into the HelioRoom Embedded Phenomenon to help students and the teacher make clear, collective progress in understanding the phenomenon. In HelioRoom (Thompson & Moher, 2006), students are told to imagine that the centre of their classroom is at the center of the Sun, and to look outward toward the walls, where they will see planets circling them. Four computer monitors are affixed to the 4 classroom walls, serving as “portholes” out into space, and coloured discs are seen to move from left to right across the monitors, each at its own constant speed, disappearing from one monitor and reappearing in the next one at the logical time (i.e. what its speed going across the monitor would predict). Slower moving planets are occluded by faster moving (and closer) ones, although all planets are the same size (see Figure 4). This forms an inquiry puzzle for students to investigate as a classroom community: what planet names should be ascribed to each coloured circle? Students are tasked with using variables of speed and occlusion to solve the HelioRoom EP challenge of identifying the “planets” orbiting around their classroom, during a 90-minute class period.



*Figure 4.* Orbiting “Brown” and “Purple” planets visible from a HelioRoom porthole.

Our first iteration of the CK application was purposed to enable students to input “notes” about each of the coloured discs, from their tablet computers (see Figure 5); which would dynamically appear on the classroom’s interactive whiteboard (see Figure 6). They also had a tablet-based observation form that allowed them to input the specific occlusion relationships, which were aggregated in real-time as a distinct representation (see Figure 7).

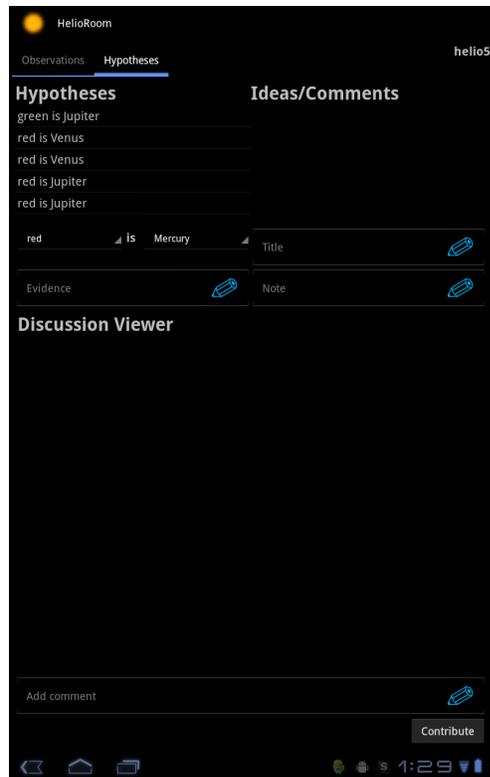


Figure 5. CK tablet interface from which students entered (1) evidence-based “Hypothesis” notes about which coloured disc represented which planet, and (2) “Idea/Comment” notes.

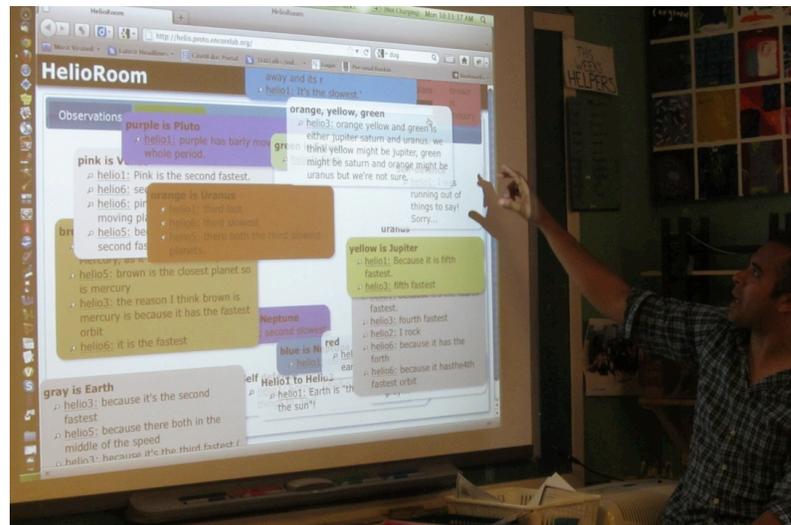
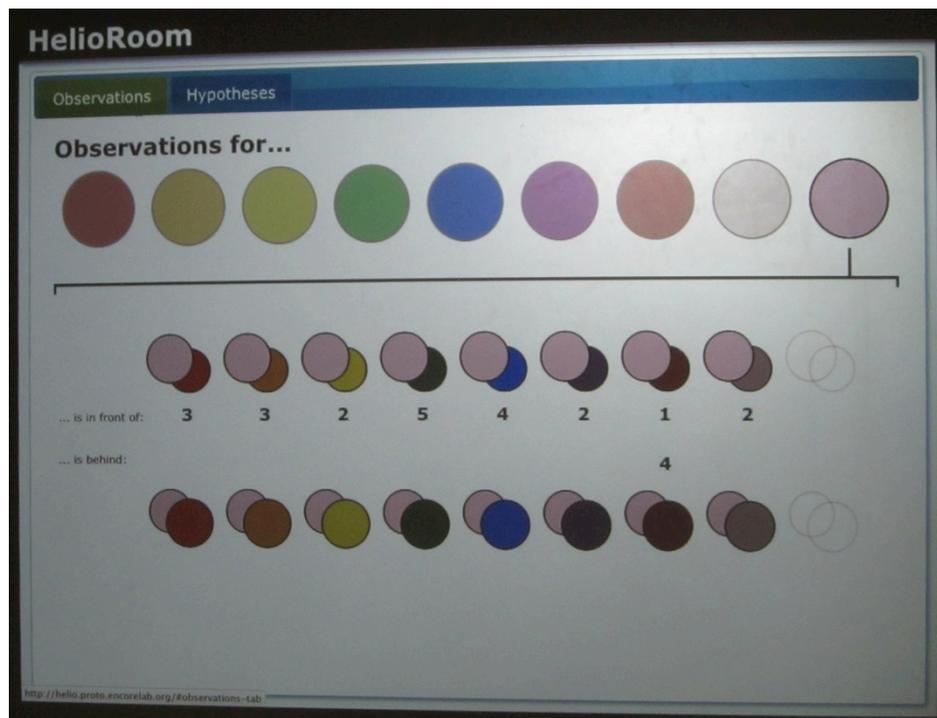


Figure 6. Common Knowledge notes publicly displayed on the classroom’s interactive whiteboard. Notes are colour-coded by hypothesis (i.e. which coloured disc represents which planet). White notes are “Idea/Comment” notes.

CK notes were used for purposes of keeping track of ideas that came up during the general inquiry, including their hypotheses about planet identities, ideas about methodologies (e.g., the use of stopwatches and strings), or evidence that was not of the specific form required by the occlusion observation form. The notes also included a tagging function, where students could choose tags from a fixed set of planet names. Once entered, the note dynamically appeared on the classroom's interactive whiteboard (IWB), in a growing cloud, as well as on all other student tablets, in a growing list. Using a combination of the aggregate representation of the circle occlusions (e.g., Figure 7) and the CK Common Board (Figure 6) teachers helped to guide student progress developing appropriate patterns of discourse that were the topic of this research.



*Figure 7.* Public aggregate display of the community's observations about the "Pink" disc/planet (e.g., 3 people observed that the pink planet occludes the orange planet, 4 people observed that the pink planet "is behind" the brown planet).

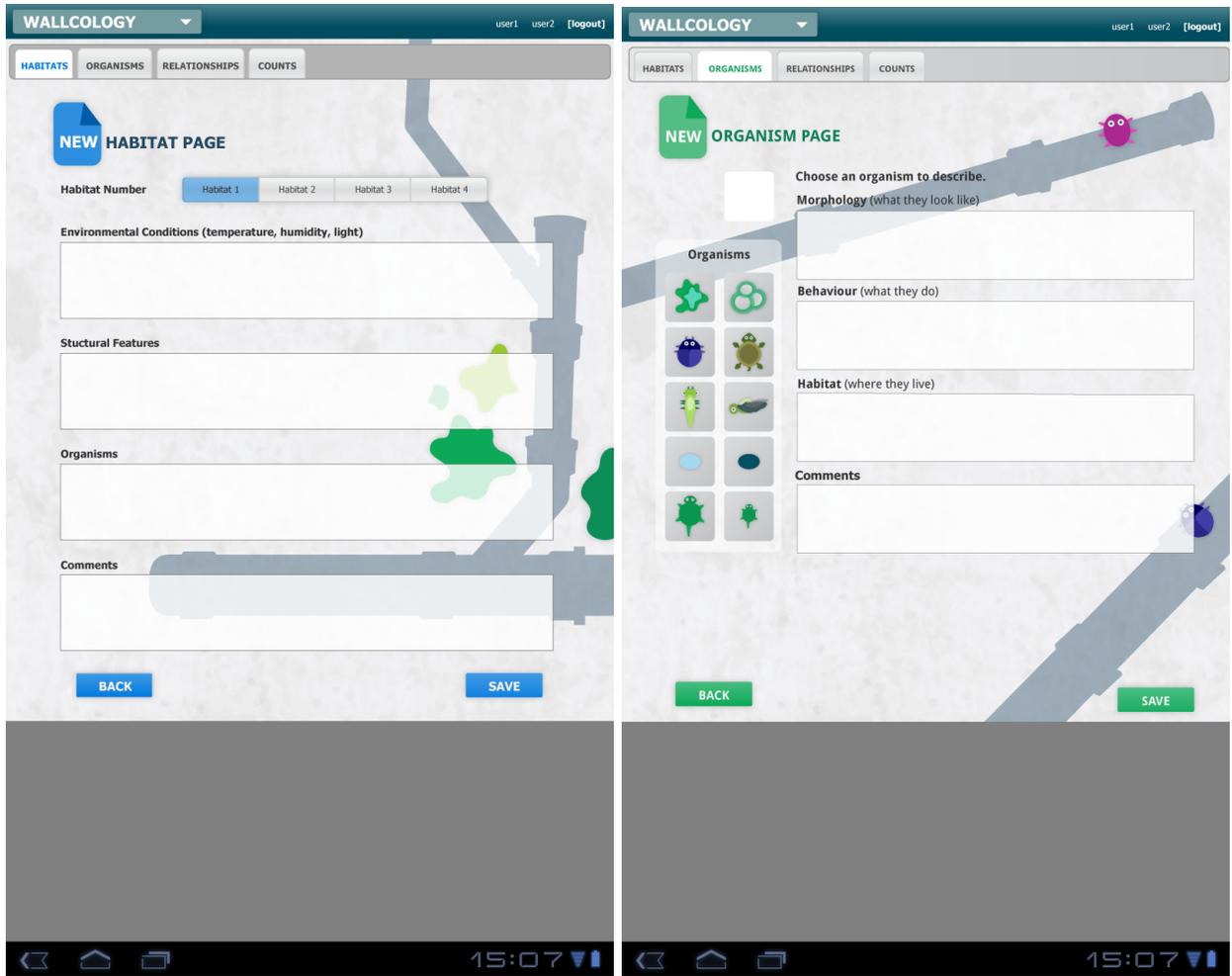
## **CK Version 2: WallCology**

The second iteration of CK was designed to support a 9-week biodiversity unit to be run in both teachers' classrooms, from October to December 2011. Like HelioRoom, WallCology is an "Embedded Phenomenon" that situates a digitally rendered phenomenon throughout the physical space of the classroom to serve as an object of inquiry for individual students, collaborating groups, and the class as a whole. In this case, the phenomenon consists of a digital simulation or microworld consisting of several species of make-believe organisms, each of which occurs in four life cycle phases (egg, larva, pupa, adult), as well as two different vegetative food sources (mold and slime). These organisms "live" in four habitats within the four classroom walls, and can be seen through computer monitors - called "wallsopes" - on each classroom wall, as the organisms crawl into the visible portion of the screen, then off again, and the eggs and vegetation sit on the various inner wall surfaces and plumbing pipes that are visible (see Figure 8). The four habitats vary in terms of temperature, light, and humidity, which drive variation in the population density of the various species. Students must investigate this ecology, determining each organism's preferred environmental conditions, uncovering the lifecycle details for the species, and discovering the ecology's food web. The teacher helps to guide students' inquiry, using a variety of digital- and paper-based representations.



*Figure 8.* Students using tablet computers to record observations of various organisms' behaviour and morphology viewed through a WallCology "wallscope" (i.e. computer screen) that allows them to "see" the organisms seemingly living within this classroom wall. The wallscope also displays the habitat's environmental conditions (i.e. light, heat, humidity).

As in the previous iteration, the EPIC research group had developed a set of interesting tools and representations to help scaffold students in their WallCology investigations (see Figures 9a-c). These technology scaffolds, and the representations they produced, served to inspire many discourse events amongst teachers and students (Cober et al., 2013), as they provided a sense of visual progress or conflict within the observational corpus of the community. CK was integrated within this suite of tools, serving to help students make observational notes and synthesizing comments about the state of knowledge within the community (including notes about emerging patterns, conflicts that may need to be resolved or topics deserving further investigation).



*Figure 9a.* Design of various software applications to support student observations of WallCology habitats (i.e., observed through the wallscope portals): Habitats, Organisms, Life Cycles, and Food Web Relationships.

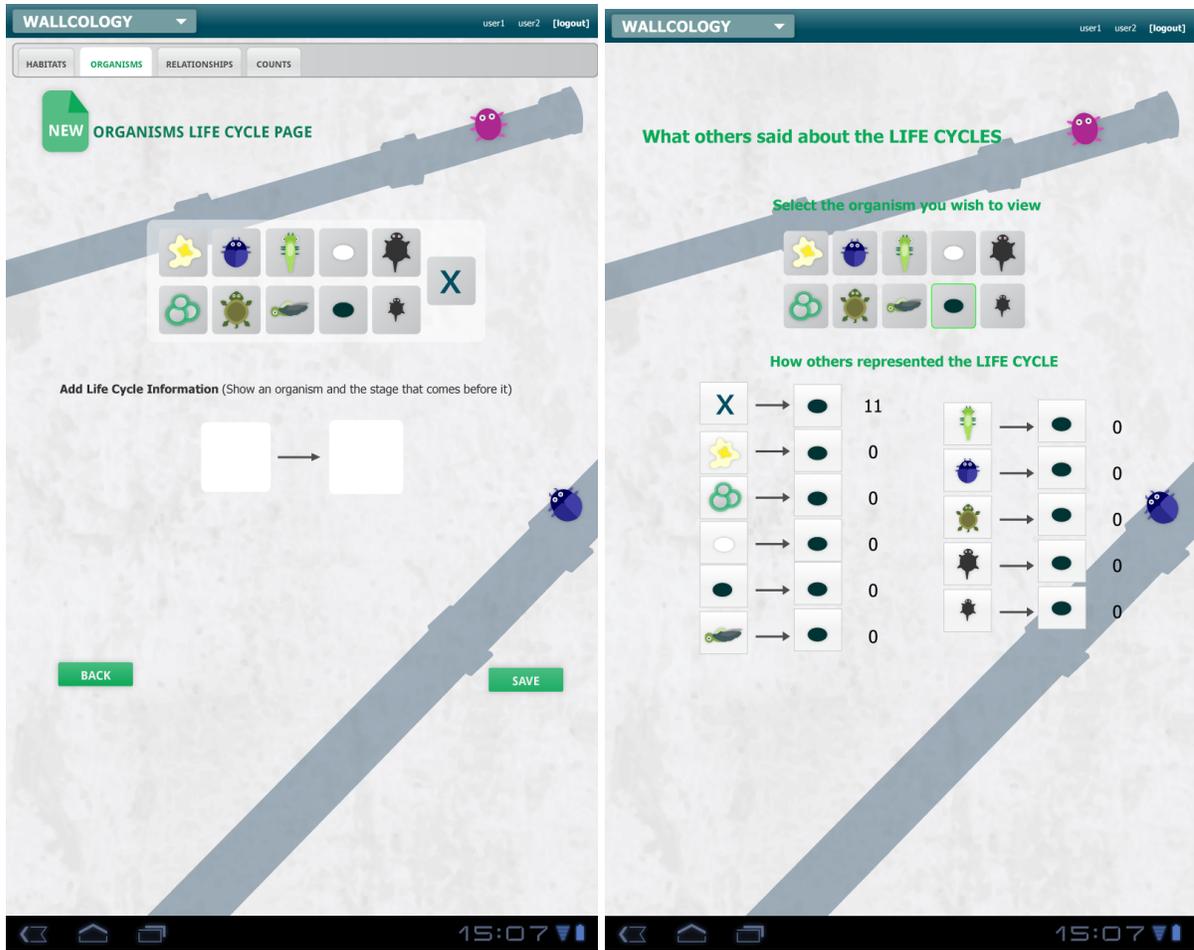


Figure 9b. Design of various software applications to support student observations of WallCology habitats (i.e., observed through the wallscope portals): Habitats, Organisms, Life Cycles, and Food Web Relationships.

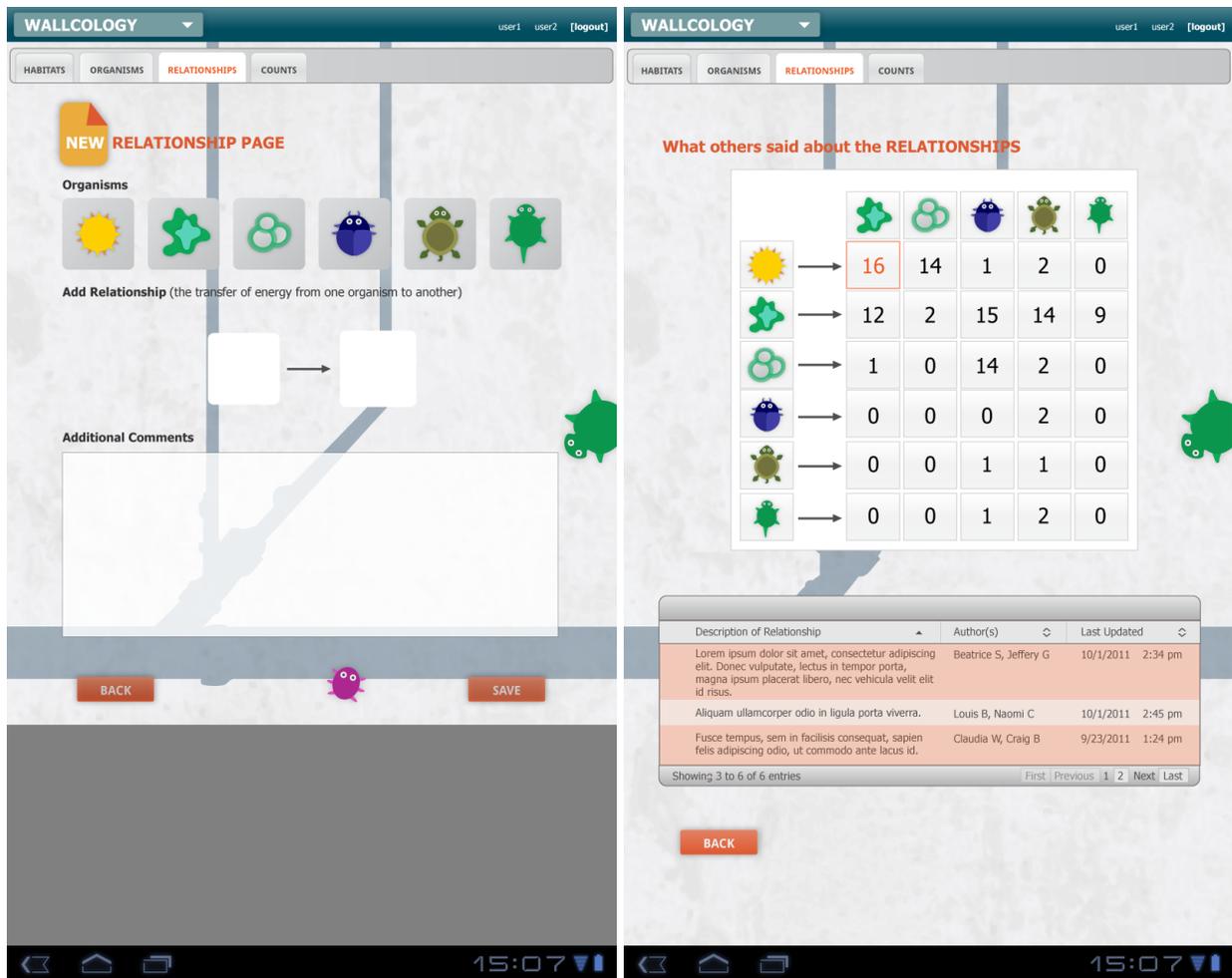


Figure 9c. Design of various software applications to support student observations of WallCology habitats (i.e., observed through the wallscope portals): Habitats, Organisms, Life Cycles, and Food Web Relationships.

Responding to our discussions of the pilot, this iteration of CK enabled learners to topically categorize (i.e. tag) their ideas, such that all notes could be filtered using these tags on the classroom’s IWB. Using their tablets, students contributed questions, evidence-based hypotheses, theories, and ideas; and “tagged” their contributions from a pre-seeded keyword list of science content (e.g., “Temperature”, “Light”, “Organism”) and practice (e.g., “Theory”, “Observation”, “Question”). All student-contributed notes also dynamically appeared on all tablets and the classroom’s IWB, with the tag words acting as note filters on the IWB. In terms

of the design of the activity sequence, “CK discussions” were conceptualized as discreet events where students were encouraged to engage in CK note-taking (see Figure 10, showing one of the planned WallCology discussions). These discussions were integrated explicitly into the WallCology curriculum script at several points in time.



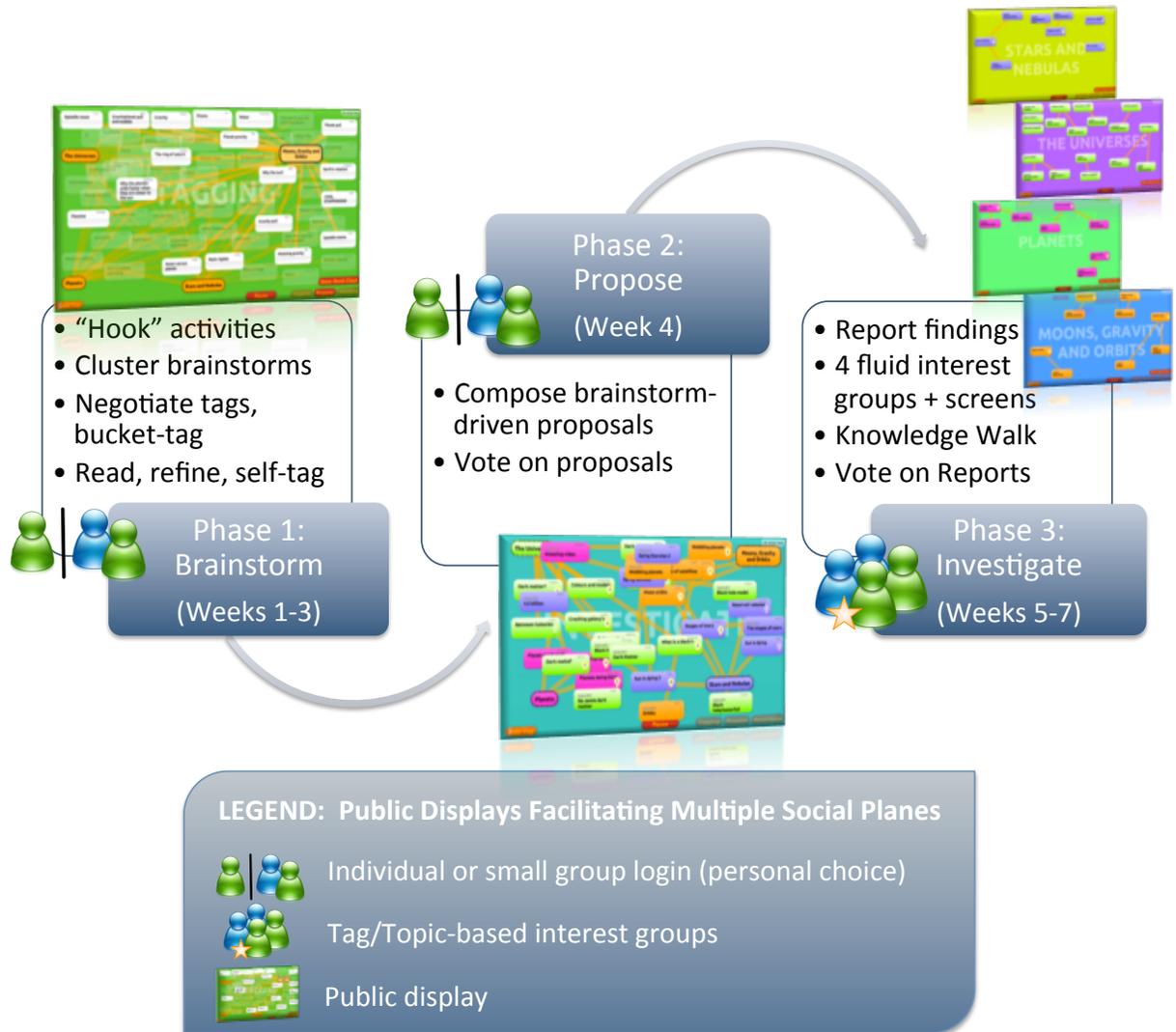
*Figure 10.* Aggregate representation of the community’s pair-wise conjectures of “what-turns-into-what”, in an effort to collectively uncover each species’ lifecycle; displayed publicly on the classroom’s interactive whiteboard. Here, Brad is facilitating a classroom discussion about possible life cycles, drawing from the aggregate data on the interactive whiteboard, and using pictures of the organisms to support the classroom discussion.

### **CK Version 3: Astronomy Inquiry**

The third iteration of CK was designed to play a more central role in the KCI script, which was devoted to a knowledge building pedagogy where the teachers lead students in developing and investigating questions relating to topics in astronomy over a 9-week time span. The two teachers were experienced in knowledge building, and acknowledged that this would

diverge somewhat from the strict interpretations of both KCI and the KB principles. However, because there was only a very short-duration EP for this topic (astronomy), our co-design team felt that this approach would be consistent with the teachers' usual methods, allowing students to define and address the inquiry topics they find most interesting, and putting CK to a very interesting new form of application. The HelioRoom EP was employed as an introductory "hook" activity, requiring only one 90-minute class period for students to uncover the planetary identities of all the coloured circles.

We developed a pedagogical script centred around CK as a knowledge building and discourse environment. Importantly, this version of CK was designed not only to collect and aggregate (using tags) student notes, but also to guide the community through three successive phases of inquiry: brainstorm, propose, and investigate (see Figure 11); scaffolding students and teachers within each of these phases. In addition to personal displays on student tablets and a public display of the community's inquiry on the classroom's IWB, this third iteration of CK included smaller public displays for fluid, self-selected small groups that were self-organized around the main topics. It also relied on the use of intelligent agents to help with the sorting and tagging of notes, and provided the teacher with specific scaffolds to advance the class between the various phases of inquiry. Dynamic word clouds on all public displays offered teachers and students a quick formative assessment of the community's trending ideas.



*Figure 11.* The 7-week CK-supported inquiry and technology script, with different public displays configured for the three phases, and students supported in various social planes.

In phase one, students began with a brainstorm of important and interesting ideas, tagged those ideas with socially negotiated tags, then built on them to develop a set of four “core categories” (see Table 2). When the teachers felt it was appropriate to switch phases (and after some important discourse moves, they advanced CK into a new phase (using controls on the IWB) where students selected a “focus topic” (from the four core topics) and then created a new kind of note called a Proposal that responded to the brainstorming content. Finally, after the

teacher again set up and enacted the phase transition, students completed Investigation notes that responded to their proposals. The investigation phase was conducted on the smaller Topic boards. The progression from Brainstorm to Proposal to Investigation notes was an innovative feature of this version, requiring a considerable level of orchestrational expertise from the teacher.

Table 2

*Each Class' Socially-Negotiated Tags – "Interest Topics" in Subsequent Inquiry Phases*

<b>Brad's Class' Tags</b>	<b>Jen's Class' Tags</b>
Stars & Nebulas	Eclipses
Moons, Gravity, and Orbits	Orbits & Seasons
The Universe	Sunrise/Sunset
Planets	Stars

Once again, the detailed designs for this iteration will be presented in Chapter 4 as an outcome of the study, where the analysis will focus on how the content of the CK knowledge base was employed by teachers as a resource for their own supportive discourse, to engage students in constructivist reflection, and to advance the inquiry within the classroom community.

### **Methodological Approach**

In general, CK has been designed to scaffold the KCI model, where students work as a knowledge community to develop a collective knowledge base, and teachers guide a community's inquiry progress by referring to their collective knowledge base (e.g., to reveal gaps that still need to be addressed, patterns that have emerged, suggesting possible next steps or open questions). In CK, this process would entail referencing and interacting with aggregate views of student-contributed CK notes, as displayed on the classroom's interactive whiteboard (IWB). An important focus of analysis will therefore be the teachers' orchestration of inquiry

through discourse that is centred on the community's emergent knowledge base, to scaffold the students' progress through inquiry activities.

In design-oriented research, it is important to distinguish between the innovation *as it is designed*, and that actually enacted. While the design might perfectly satisfy all the theoretical and methodological goals, many things could transform the actual enactment into a totally different intervention. The technology could fail, or the teacher could abandon it partly (or entirely), resulting in some “lethal mutation.” To analyze student outcomes as if they derive from the *designed* intervention would be wrong. Further, for some designs (as in the case of CK), there are aspects of the intervention that only *emerge* in the course of enactment. In other words, we created a platform and some material formats to support certain interactions, but left much of the script “unbound” to emerge or evolve with the classroom enactment. For example, the design did not stipulate when teachers should pause student activities for discussion, or what kinds of instructions they should give to help students focus their notes. We left those to emerge as an object of study – particularly in regard to the kinds of discourse that occurs, and the referencing of community knowledge.

As such, this study does not seek to identify any discourse method as being advantaged over another. Rather, the aim is to uncover the specific forms of discourse that appear as a consequence of enactment. That is, how did teachers interact with students, in a CK-mediated learning environment, in order to achieve progress within a sequence of activities defined according to the KCI model? This research precedes any potential study of the relationship between CK, KCI and student learning outcomes. Following a design-oriented methodology, the study advances CK through several iterations to inform our understanding of the interdependencies of pedagogical design, technology-scaffolded inquiry environments, and

various forms of interaction and discourse that emerge as a consequence. Once these systemic relationships are understood, we may, for example, vary the technology elements or inquiry scripts to see if the resulting teacher-guided discussions could produce improved student outcomes. Until we have a good understanding of these relationships, even within the confines of KCI research, it is not possible to make clear empirical connections to student learning outcomes.

### **Activity Systems and Design-Based Research**

The design of a scaffolding technology environment like CK requires an understanding of how teachers orchestrate inquiry using discourse that engages students in reflection about their progress (including any representations or rehearsals of knowledge within the community). Hence the need for research of discourse and activity sequences in technology-mediated inquiry environments. Such sequences must be examined in the context of an overarching activity system to understand how the Common Knowledge technology, teacher-guided discourse patterns, and the inquiry activity script inter-relate to function as a coherent whole. Furthermore, because the technology and script are designed for a specific classroom context, they must be enacted in the classroom contexts for which these are designed, connecting educational research to practice (Wang & Hannafin, 2005; Cobb et al., 2003; Design-Based Research Collective, 2003).

For this research, an adaptation of Activity Oriented Design Methodology (AODM, as discussed in Chapter 2) has guided the iterative design and evaluation of CK, capturing the community's inquiry activities, interactions with technology, and teacher-guided community discourse (see Figure 12).

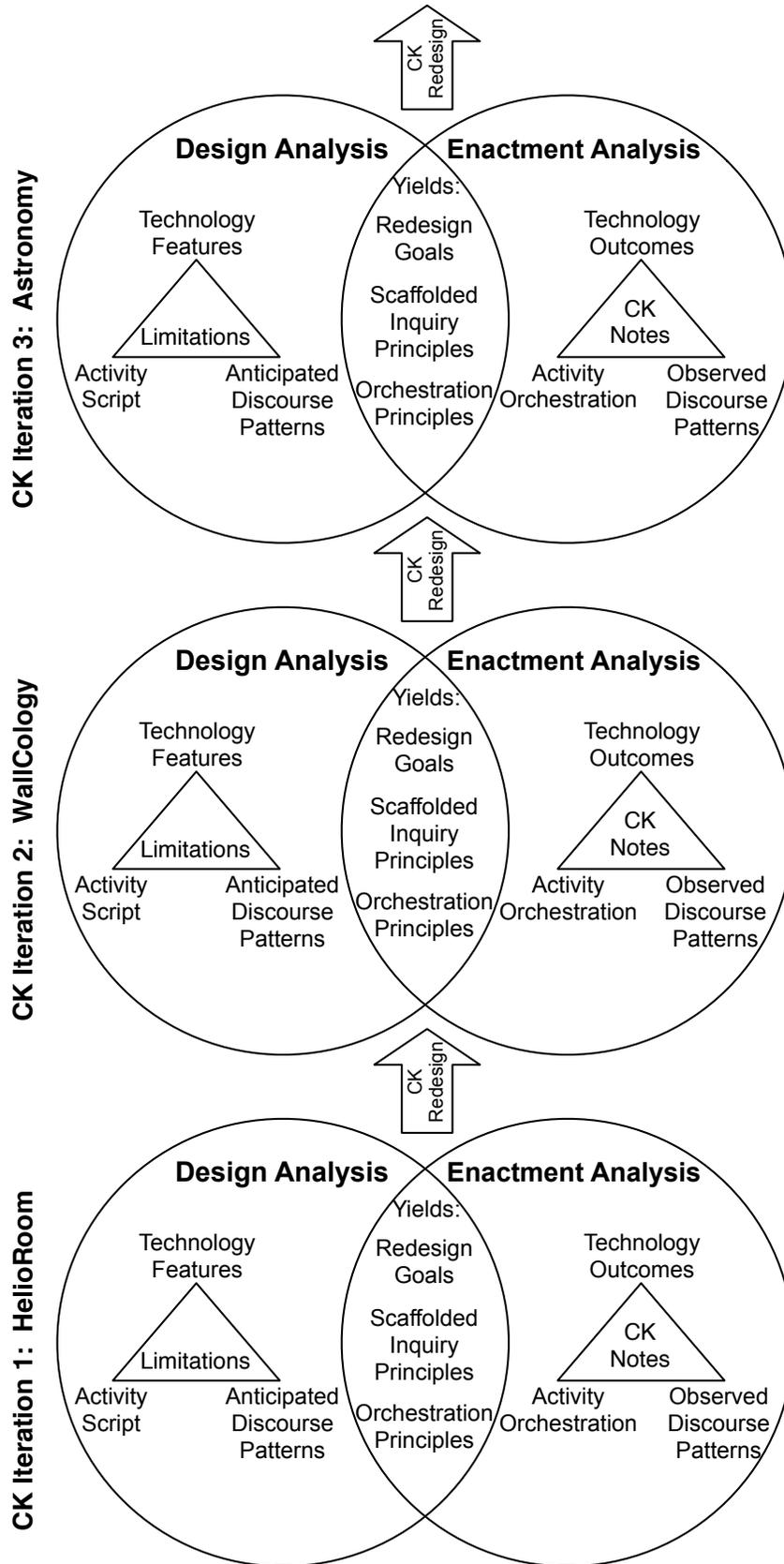


Figure 12. Design and enactment analyses according to the technology, scripting, and discourse dimensions, for three iterations of Common Knowledge (CK).

## Design and Enactment Analyses

For each iteration of CK, I first analyze the *design* according to three dimensions: (1) technology features, (2) anticipated activity sequences or “script”, and (3) expected discourse patterns. I then analyze the *enactment*, according to the same three dimensions, which typically departed somewhat from what was designed, and brought in complementary aspects as well. Hence, in all classroom sessions that employed CK, I observed and recorded the usage of technology, the patterns of activity, and all major episodes of teacher-guided discourse. These are contrasted with the patterns we had targeted or expected in our design, leading to insights to guide the next iteration of technology features for CK, as well as an increasingly sophisticated understanding about how CK should be used, and the most suitable or effective forms of inquiry discourse. In this way, CK progressed from being a stand-alone inquiry tool, integrated with other tools (i.e., in HelioRoom and WallCology) to serving as the central technology environment for the orchestration of a 9-week KCI Astronomy unit.

As described, (see Figure 12) each iteration of Common Knowledge can be seen as comprising 3 dimensions: (1) technology features, (2) activity script, and (3) discourse patterns, which correspond roughly to the 3 research questions presented in Chapter two. These dimensions can be defined as follows:

1. *Technology Features* - e.g., community and individual displays, user interfaces, prompts, visualizations, tagging options, and temporal features.
2. *Activity Script* - Planned activities and sequences of student work that are connected with use of the CK environment. The development of the script is concerned with timing (i.e.,

when CK should be used, and for how long), conditions (i.e., specifying when, and which students may go into which groups, receive which materials, etc), and the role of CK discussions within the overarching curricular unit (e.g., 9-week inquiry unit on biodiversity, or astronomy).

3. *Discourse Patterns* – How teachers engage with the emerging content of the CK knowledge base, including any reflective statements they make, interactive prompts given to individual students or the whole class (e.g., questions or challenges), and pedagogical techniques that leverage CK for the advancement of inquiry (e.g., by synthesizing content and responding to patterns in such a way that students gain insight or inspiration to progress in their investigations or epistemic understandings).

For each iteration, I begin with a design analysis that describes the iteration’s design in terms of technology features, activity script, and expected patterns of discourse. It also includes a description of how the design responded to revision goals that came from the previous iteration. *Technology features* will describe the features of individual and community interface environments, and how they responded to any design revision goals from the previous iteration. *Activity script* will describe goals for content and inquiry process, student and teacher patterns of interaction sequences, and any expected activity sequences (i.e. “phases” of the inquiry) that were designed to achieve the goals. *Expected discourse patterns* will characterize expected patterns of discourse that we felt were likely or important.

Next, I will present an enactment analysis to examine what actually occurred, drawing on evidence from data sources including students’ note contributions and video-recorded discourse events. Specific enactment coding will address:

1. *Technology use and outcomes*: Describe whether the technology worked as envisioned, and if any features were used in unanticipated ways. Discuss technological constraints and failures, as well as corresponding consequences.
2. *Activity orchestration*: Describe the inquiry activities and sequences that occurred, including duration of activities, number of student-contributed CK notes, and other interactions with CK, including tagging, sorting, filtering, and applying or extending the CK knowledge base to inquiry.
3. *Discourse patterns*: Focus on teacher-guided oral discussions, including how CK content was used to inform these discussions, and the outcomes or consequences, in terms of pedagogical instructions that re-focused students' subsequent inquiry. Patterns of discourse will also be coded, revealing possible progressions in the nature of these patterns over time, or differences between the two teachers.

The enactment analysis will evaluate how CK was used in ways that differed from what was envisioned during design. It will also return a set of goals for the design of the next iteration, including suggestions for new technology features or scaffolds, design principles for inquiry sequences or discourse patterns, and design principles for teacher orchestration of inquiry. These principles can be discussed in terms of their support for a knowledge community approach to inquiry, such as KCI.

### **Data Sources**

Data sources will include classroom observation notes, data log files, video and audio recordings, as well as teacher and student interviews. The enactment of the designed curriculum will be mapped onto the KCI model to examine alignments and the role of teacher- and student-

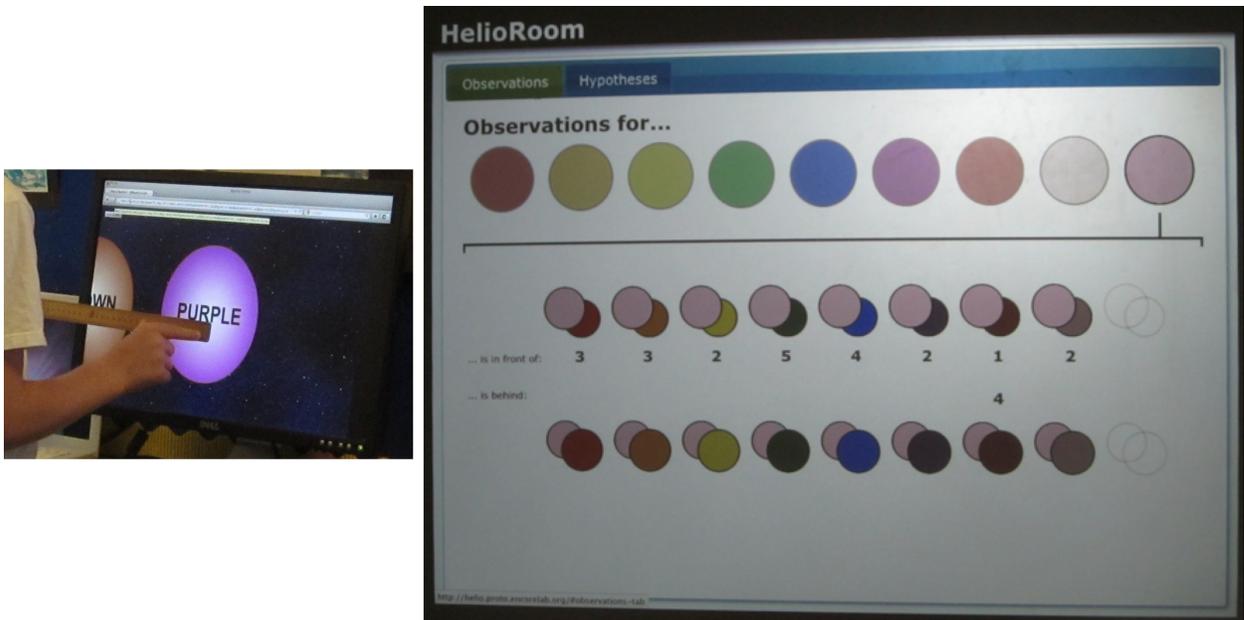
initiated discourse within the KCI model. Interview data will be analyzed for teacher and student perspectives of the inquiry experience. Video, discourse, and content analyses will be done to further investigate (1) how teachers orchestrated the flow of inquiry activities, technology, incoming knowledge contributions from students and classroom discussion; and (2) the effect of teachers' discourse moves on the knowledge community's inquiry.

## Chapter 4: Iteration 1 and 2 Findings

Following the pilot study, Common Knowledge was redesigned with the intention of integrating it within a sequence of activities (i.e., a script) that supported student inquiry of the HelioRoom Embedded Phenomena (EP). As discussed in Chapter 3, the HelioRoom EP is a persistent (i.e., ongoing) room-sized simulation that uses wall-mounted computer displays to immerse students in the planetary motion of our solar system, situating the Sun in the center of their classroom. Unidentified planets, seen as coloured discs through a “porthole” (computer display) mounted on each of the classroom’s four walls, perpetually orbit around the classroom (Thompson & Moher, 2006). Students observe the speed and occlusion of planetary relations, to identify which coloured discs correspond to which planets on our solar system.

### **CK Version 1: HelioRoom**

This first iteration of CK was integrated with the HelioRoom tablet application, which was designed to enable student observations of planetary occlusions, and to visualize the community’s aggregate observational data. Both teachers enacted this first iteration of Common Knowledge with their grade 6 students, as each class engaged in a 90-minute session to solve the HelioRoom puzzle. The objective of iteration 1 was to support students in making reflections about their HelioRoom observations, including hypotheses about which planets from our solar system might correspond to particular orbiting coloured discs in HelioRoom, and why. Figure 13 shows the components of the HelioRoom inquiry components, including: (1) a porthole from which coloured discs may be seen orbiting the classroom, and (2) the aggregate display of the collective observational database to which students contributed from the HelioRoom tablet app.



*Figure 13.* The components of HeliRoom inquiry (left to right): a porthole from which coloured discs may be seen orbiting the classroom, the aggregate display of the collective observational database to which students contributed from the HeliRoom tablet application.

### **CK Version 1: Design Analysis**

Across all iterations, Common Knowledge pursued the general goal of enabling students to contribute their ideas to a collective knowledge base, to access their peers' ideas, and to visualize the community's ideas. The general approach includes a separate tablet interface for individual use (i.e. for independent student knowledge work), and an Interactive White Board (IWB) interface for community use (i.e. for teacher-guided community knowledge work). The specific forms and functions of the tablet and IWB applications were subject to revisions with each iteration, with new features added, and increasingly sophisticated roles for intelligent agents that allowed new ways of integrating Common Knowledge into the broader inquiry curriculum. The next four sub-sections will analyze the design of iteration 1, capturing its specific technology, activity script, and discourse expectations.

Based on the pilot study of Common Knowledge, it was observed that the student technology should support peer responses to notes, including “read” access to CK notes from students’ tablets. It was also observed that the rigid table format of the public IWB interface did not leverage the interactive capabilities of the IWB technology, and constrained the ways in which the community could publicly work with the knowledge during whole-class discussions. Furthermore, teachers indicated that continuously monitoring the public IWB display for students’ incoming notes, in addition to managing the class, was a taxing activity – despite the fact that they were only working with half their normal class size of 23 students. These insights were assembled into a set of redesign goals for iteration 1 (see Table 3).

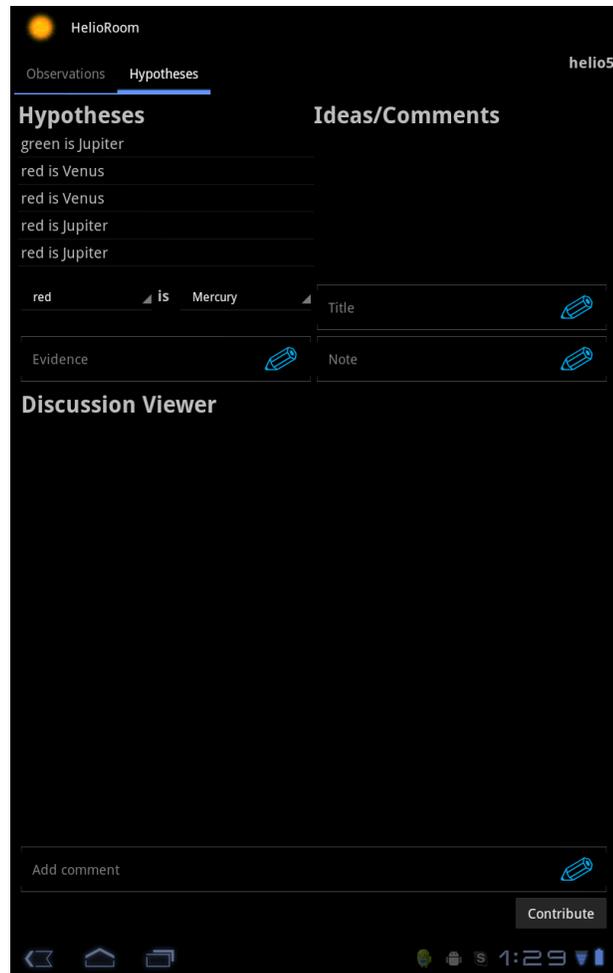
Table 3  
*Redesign Goals for CK Iteration 1*

	<b>Limitations of Pilot Version</b>	<b>Redesign Goals for Iteration 1</b>
<b>Individual Tablet Interface</b>	No "read" access to community's notes.	Enable "read" access to community's notes.
	No response/build-on "write" capabilities.	Enable response/build-on "write" capabilities.
<b>Public IWB Interface</b>	Rigid "Inquiry" vs. "Idea" table constrained ways in which community could work with knowledge (notes) during community discussion.	Offer more flexible ways in which community could work with knowledge (notes) during community discussion.
	Did not leverage interactivity of IWB technology.	Leverage interactivity of IWB technology.
	Heavy orchestration load on teachers to monitor incoming notes and manage classroom concurrently.	Reduce teachers' orchestration load.

### **CK Version 1 Design: Technology Features**

The HelioRoom tablet interface included a “Discussion Viewer” which enabled students to scroll through a list of the community’s notes (which had two possible types: “Hypothesis”

and “Idea”) viewable by title. Selecting a title opened the note, which included the original student note and any responses (i.e., build-ons) attached to the bottom of the note. The tablet interface scaffolded students’ hypothesis formulation through the use of two interlinked drop-down menus (i.e. <choose disc colour> IS <choose planet>) and a required text input field called “Evidence” where students had to include some statement before they could post their hypothesis (see Figure 14). While it may be argued that constraining the scope and form of hypotheses in such a manner limited the possibility of using CK outside of the HelioRoom context, such well-defined scaffolds maintained students’ focus on identifying colour-planet pairings to solve the HelioRoom puzzle, and enabled the evidence-based hypotheses to be visually represented in an aggregate format that was efficiently accessed and easily understood (see Figure 15) by the community. Since the students worked in pairs for the HelioRoom activity, the tablet interface also provided a common reference to ground oral inquiry discussion within student dyads (cf. Clark & Brennan, 1991).



*Figure 14.* The tablet interface for iteration 1, from which students entered evidence-based “Hypothesis” notes about which coloured disc represented which planet, and “Idea” notes.

The community IWB interface represented the two kinds of notes as follows: (1) “Hypothesis” notes were colour-coded and aggregated such that all hypotheses for a particular color (e.g., the blue disc) were concatenated together, and (2) “Idea” notes appeared in white colour, in “fully open” boxes (i.e., due to technology development schedule, we could not have teachers touch note icons to open or close into title-only icons), that could be dragged around the IWB. The use of colour provided at-a-glance information – even from a distance in the classroom – to serve as a source of information about trends or progress in the community’s ideas. Consistent with other note-sharing systems, we included the capability for students to

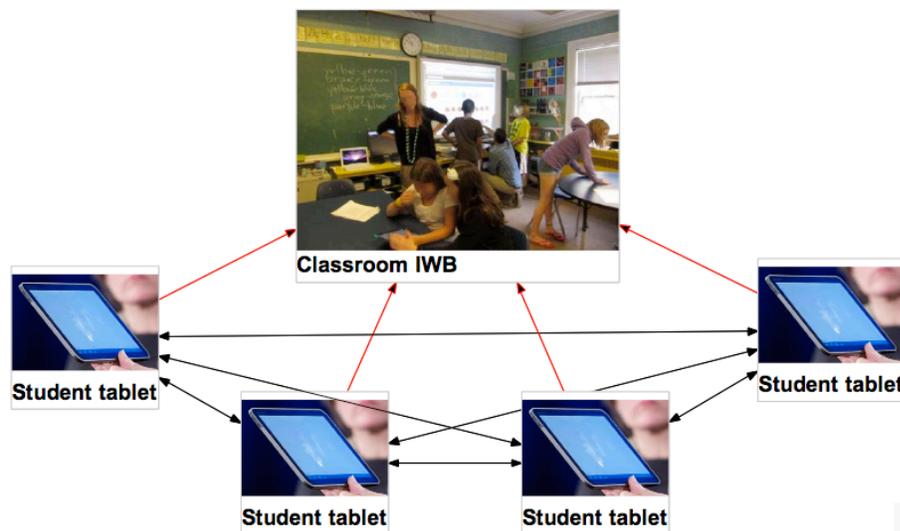


The grouping of hypotheses by color, and concatenation of ideas with build-ons responded to the redesign goal of reducing teachers' orchestration load by alleviating some of the burden of conceptually grouping topically related information and visually grouping it in explicit visual format. Each note could be dragged around on the IWB workspace, offering opportunities for the teacher or students to work with the ideas, while also responding to two other redesign goals, as shown in Table 4 below. The aggregate view of the community's ideas and evidence-based hypotheses about colour-planet pairings provided a "grounding reference" (Clark & Brennan, 1991) for the community's oral discussions. Table 4 summarizes technology features of iteration 1 that responded to redesign goals stemming from the pilot version.

Table 4  
*Iteration 1 Technology Features That Respond to Redesign Goals*

	<b>Redesign Goals for Iteration 1</b>	<b>Response to Redesign Goals</b>
<b>Individual Tablet Interface</b>	Enable "read" access to community's notes.	"Discussion Viewer" indexed community notes and gave access to note contents.
	Enable response/build-on "write" capabilities.	When viewing a note from "Discussion Viewer", build-on the note via the "Add comment" text field.
<b>Public IWB Interface</b>	Offer more flexible ways in which community could work with knowledge (notes) during community discussion.	Movable note threads, unstructured workspace.
	Leverage interactivity of IWB technology.	Movable note threads allowed for possibility of dragging notes into topic clusters, then labeling a cluster using the IWB's digital ink pen.
	Reduce teachers' orchestration load.	Evidence and build-ons visually appended (and conceptually grouped) as part of the root Hypothesis or Idea note thread.  Note threads colour-coded by hypothesis disc colour, or appeared white if it was an Idea. Colours provided at-a-glance formative assessment of community's idea trends, even from a distance in the classroom.

Technological adjustments in this first iteration allowed students to access all notes in the collective knowledge base directly from their tablets, resulting in more multifaceted student interactions (see Figure 16 - Fong et al., 2012). For example, if a student dyad read a peer's Idea note (including its build-ons) from their tablet, they could further build-on the Idea, resulting in a growing idea note thread displayed on the IWB.



*Figure 16.* The red arrows illustrate student interaction patterns mediated by Common Knowledge in the pilot version, which did not offer tablet “read” access to the community’s notes, nor did it support “build-on” note responses. The black arrows illustrate new opportunities for student interactions in Iteration one of CK, including access to all community notes, and the capability of responding to peers’ Idea note threads from their tablets.

### **CK Version 1 Design: Activity Script**

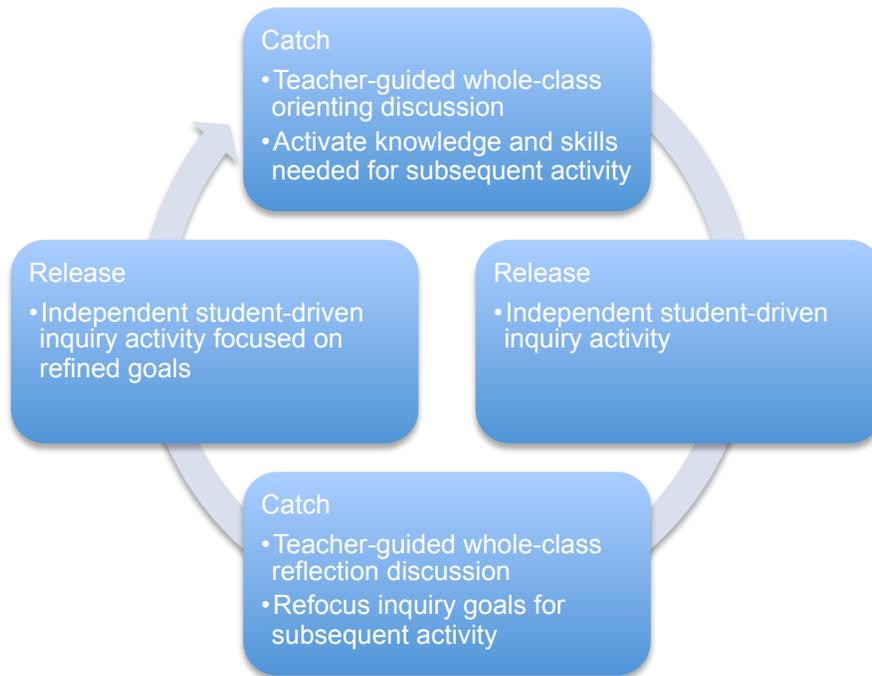
The goal of inquiry activity for iteration 1 was to have students “solve” the HelioRoom puzzle by determining which colored discs from the HelioRoom EP corresponded with which planets in our solar system. To achieve this, the community first had to amass a collective database of observations about planetary occlusions, using the HelioRoom tablet application. They then had to draw connections between the aggregate observational data and their own

knowledge of the solar system's planetary order, to inform hypotheses that were added using Common Knowledge. Finally, as a community, they had to draw on their collective knowledge base of observations and hypotheses, to deduce the colour-planet pairings of the HelioRoom puzzle.

The activity script assumed that students would work autonomously as dyads, observing the interaction of coloured discs on any of the four HelioRoom portholes and adding their observational data using the HelioRoom tablet app. Each dyad was given a tablet computer to record observational data in the HelioRoom app, and to contribute hypotheses, ideas, and questions in the Common Knowledge portion of the app. Students also had access to writing materials, paper, rulers, and stopwatches that they could use freely in support of their inquiry activities (Cober, McCann, Slotta, & Moher, 2012). We designed Common Knowledge to support this inquiry model, where students could share their thoughts using an open "Idea" note format whenever they wanted to contribute ideas or questions, and a structured "Hypothesis" note format when they thought they had good reason to assert a coloured disc's planetary identity.

The pilot study (see Chapter 3), had revealed a "Catch-and-Release" orchestrational pattern – where teachers first catch the community's attention in an orienting discussion that serves to orient students and activate the knowledge and skills they would need for the subsequent inquiry, then "release" the students for a period of independent inquiry work (Figure 17). During the independent "release time", the teachers circulated among student work groups to monitor their progress, probe their thinking, challenge any misconceptions, and respond to questions, while also monitoring the community's growing ideas as represented on the IWB. When the teacher noticed a sufficient amount of progress, or lack thereof, s/he would then

“catch” the community’s attention again and guide them in another oral reflection about the state of the community’s knowledge, using the IWB as a resource. This discussion would conclude with instructions or reminders to students, and then a “release” of students again to work independently, focusing on the inquiry goals that had just been discussed. Based on this observation from the pilot study, we expected this Catch-and-Release activity pattern to recur, although we recognized that the inquiry activity of HelioRoom was different from the pilot context (a daily news discussion). Still, Catch-and-Release provided the basis of our assumptions about activity sequences that would occur in iteration 1 of Common Knowledge.



*Figure 17.* The Catch-and-Release activity pattern teachers used in the pilot enactment.

### **CK Version 1 Design: Expected Discourse Patterns**

In debriefing interviews after the pilot enactment, teachers stated emphatically that the quantity and quality of student contributions in the Daily News discussion had exceeded that of

their regular, oral Daily News discussions. This suggested that students had put more thought into their CK-mediated contributions, aware that their written ideas had an element of permanence, and that they would be read and responded to by an audience of their teacher and peers during the community discussion. Teachers also noted that the less talkative children in their class, who normally say very little in the Daily News discussion, were better able to share their ideas using CK. While the more vocal children participated actively in community discussions during teachers' "Catch" phases of orchestration, the sequential nature of oral discourse in a limited period of time inevitably resulted in missed opportunities for less vocal children to contribute to the discourse. Yet during the "Release" phases of orchestration, all children had equal opportunity to share their ideas and access their peers' ideas using Common Knowledge.

While we noted the teachers' enthusiasm, and the seemingly natural progression of Catch-and-Release, we entered CK Iteration 1 with no explicit expectations about the nature of discourse that would connect the contents of CK with the broader inquiry context of the HelioRoom simulation, or the wider context of the astronomy unit. It was assumed that teachers would employ the IWB interface as a grounding reference for community oral discussion – perhaps drawing the community's attention to some student-contributed notes for further reflection or to orient them to possible new directions. We also assumed that students would use the individual tablet interface as a grounding reference for their own small-group discussions with peers and the teacher. This was our first real implementation of CK, and we went into it with a fairly blank slate as to what kinds of written contributions and verbal discussions would occur. In the sections below, I analyze the enactment of iteration one, including technology outcomes, activity patterns, and discourse patterns.

### CK Version 1: Enactment Analysis

Both teachers successfully enacted Common Knowledge with their grade 6 students during a 90-minute session in which both classes were generally successful in solving the HelioRoom puzzle. Table 5 summarizes the correct HelioRoom colour-planet pairings, as well as the results from each class, including the order in which the class arrived at consensus on the pairings during community oral discussion. Note that the fastest and slowest moving planets were typically the first ones to be correctly identified, because of a wealth of evidence (i.e., the fastest discs were moving faster than all others, and the slowest discs were being overtaken by all others). The medium speed planets – Saturn, Jupiter, and Uranus – turned out to be the most contested and difficult to solve. The following four sub-sections analyze the technology, activity sequences, and discourse patterns seen in the CK iteration 1 enactment.

Table 5  
*Solution to the HelioRoom Puzzle, and Each Class' Solution Results*

Correct Planet- Colour Pairings		Brad's Class		Jen's Class	
		Hypotheses	Order solved	Hypotheses	Order solved
Mercury	Brown	✓	1	✓	1
Venus	Pink	✓	2	✓	2
Earth	Red	✓	3	✓	3
Mars	Grey	✓	4	✓	6
Jupiter	Green	✓	9	✓	8
Saturn	Yellow	✓	8	✓	7
Uranus	Orange	✓	7	✓	9
Neptune	Blue	Purple	6	✓	4/5
(Pluto)	Purple	Blue	5	✓	4/5

### CK Version 1 Enactment: Technology Outcomes

Teachers did use the community IWB display as a reference for guiding community discussions, often referring to student-contributed notes as a means of guiding oral reflections,

moving the note to a more visible location on the IWB, or juxtaposing it alongside other notes for comparison (e.g., when there were multiple hypotheses threads for the same disc colour). During independent student work periods, teachers intermittently checked the IWB for incoming notes, sometimes dragging note threads into related topic clusters, which they planned on referring to in subsequent community discussions.

During the 90-minute session, Brad's students contributed 66 notes and Jen's students contributed 60 notes using Common Knowledge. Figure 18 shows the proportion of note types submitted by each class. Since Brad's students were accidentally not informed about the build-on capability, none of them contributed any build-ons to peer notes. In contrast, 35% of notes contributed by Jen's class were build-ons. In Brad's class, one author group, called "Helio1," did manage to achieve an alternate form of build-on by contributing four Idea notes that were explicitly titled in a way to indicate that their contribution was a response to another group's note (e.g., "Helio1 to Helio3"). Although teachers did not explicitly state that students should contribute build-ons to their peers' notes, we see that students who knew of this functionality (i.e. Jen's students) and even one group who was not (the inventive group of Brad's mentioned above) found it useful to their collaborative knowledge work. This observed pattern of enactment validates our response to the redesign goal for iteration 1: to include build-on/response capabilities in Common Knowledge.

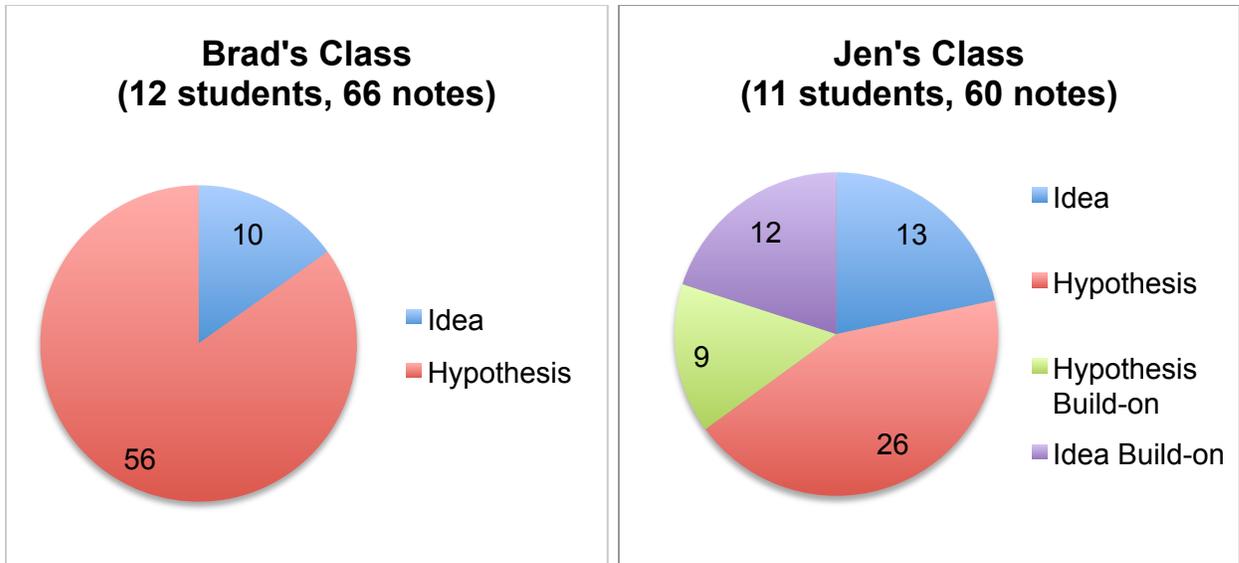


Figure 18. Note contributions from Brad’s and Jen’s classes, by note type.

Table 6  
Inquiry Scoring Rubric for Hypothesis Notes

Rubric: Inquiry Scoring of Hypothesis Notes		
<ul style="list-style-type: none"> <li>• <i>Goal</i>: accurate, well-justified hypotheses</li> <li>• <i>Accurate</i>: hypothesis pairs a HeliRoom coloured disc with the correct solar system planet</li> <li>• <i>Well-justified</i>: hypothesis is supported by observational data of the HeliRoom EP simulation, and by knowledge of the solar system</li> </ul>		
Score	Definition	Example
3	Accurate and well-justified	<i>Brown is undoubtedly Mercury, as it is the fastest by far.</i>
2	Inaccurate (i.e. wrong disc-planet pairing) but well-justified; OR Accurate (i.e. correct disc-planet pairing) but not well-justified	<i>Blue is Pluto, because it is farthest from the Sun.</i> (Inaccurate because Blue is only the second slowest disc, well-justified because Pluto is farthest from the sun and therefore the slowest orbiting planet.)

		<i>Orange is Uranus (accurate) Pretty obvious, eh? (Not well-justified.)</i>
1	Inaccurate (i.e. wrong disc-planet pairing) and not well-justified	<i>Gray is Earth (inaccurate) because they're both in the middle of the speed. (Not well-justified.)</i>
0	Off-topic, unrelated to the inquiry task at hand, or empty note.	<i>Green is Mars (inaccurate) eeepp obiklobw. (off-topic)</i>

All notes were scored according to one of two rubrics inspired by the Knowledge Integration construct (Lee & Liu, 2010; Linn & Eylon, 2011; Liu, Lee, Hofstetter, & Linn, 2008). Hypotheses notes were scored for: (1) the accuracy of information, and (2) how well-justified the claim was (see rubric, in Table 6). Idea notes were scored for: (1) the accuracy of information, and (2) how productive or generative the note was, in terms of advancing the collective inquiry (see rubric, Table 7). Figure 19 summarizes the average scores of students' notes, for both classes, by note type. Because the notes were rather terse, and there was not great need for protracted ideas (ie, the justification of which planet was which colored circle could typically be done in a line or two), the coding of notes in this case was somewhat nuanced – often needing to be determined by the presence of a single word or phrase.

Table 7  
*Inquiry Scoring Rubric for Idea Notes*

<b>Rubric: Inquiry Scoring of Idea/Comment Notes</b>		
<ul style="list-style-type: none"> <li>• <i>Goal: accurate, productive ideas that contribute to the collective inquiry</i></li> <li>• <i>Productive: testable ideas, suggestions of different inquiry approaches, acknowledgement of knowledge gaps</i></li> <li>• <i>Accurate: factual statements about the inquiry task at hand, factual subject-matter content information.</i></li> </ul>		
<b>Score</b>	<b>Definition</b>	<b>Example</b>
3	Accurate and productive.	<i>The closer to the sun the planet is, the faster it goes. (Implies that the faster a HeliRoom disc seems to orbit,</i>

		the closer it is to the sun – accurate.)
2	Accurate but unproductive, OR Productive but inaccurate.	<i>Gray is ahead of green in porthole 3! (accurate) What's gray???</i> (unproductive)
1	Inaccurate and unproductive.	<i>What planet do you think is Uranus?</i>
0	Off-topic, unrelated to the inquiry task at hand, or empty note.	<i>Sorry... I had run out of things to say!</i>

20% of all note types from both classes were independently scored against these rubrics (Tables 6 and 7), by me and this study's second rater, who is a graduate student in the final stages of a Master's program in "Curriculum Studies and Teacher Development", with four years experience as a preservice teacher educator at a major Canadian university, 12 years experience as an elementary math education consultant at a large urban Canadian public school board, and five years of experience as an elementary classroom teacher in the same school board. Inter-rater agreement was 82.6%, with Cohen's Kappa = 0.64. While rater training included informing her of the classroom context, giving her the HelioRoom answer key, and explaining the components of Hypothesis and Idea notes, inter-rater disagreements still emerged. Patterns of inter-rater disagreement were related to the rater's limited understanding of the classroom context, the rater's unfamiliarity with the subject-matter content, and the rater's limited understanding of CK note properties (e.g., a Hypothesis note's title is the actual hypothesis).

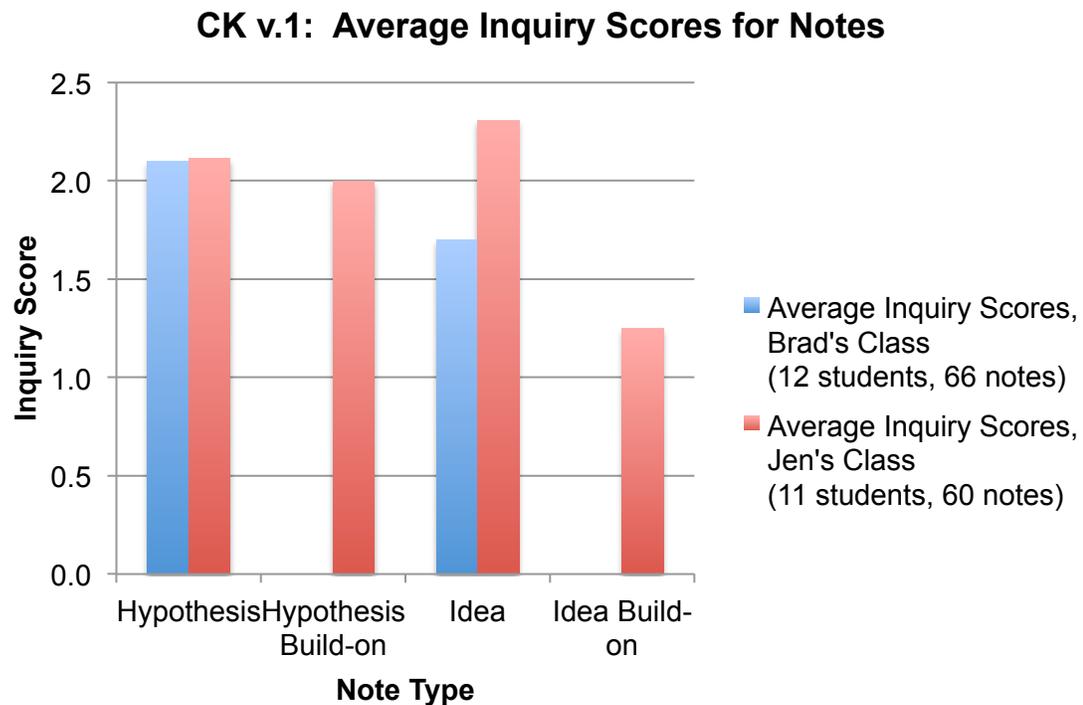


Figure 19. Average inquiry scores, by note type, for each class.

A two-tailed two-sample Student's *t*-test assuming equal variances was performed to compare both class' mean Inquiry Scores of Hypothesis notes and Idea notes. The mean Inquiry Scores of Hypothesis notes contributed by Brad's class ( $M = 2.05$ ,  $SD = 0.70$ ,  $N = 56$ ) was somewhat higher than Hypothesis notes contributed by Jen's class ( $M = 2.12$ ,  $SD = 0.86$ ,  $N = 26$ ), with  $t(80) = -0.35$ ,  $p = 0.73$ ; this difference was not significant presumably due to the small number of CK notes. Mean Inquiry Scores of Idea notes contributed by Jen's class ( $M = 2.31$ ,  $SD = 0.63$ ,  $N = 13$ ) was somewhat higher than Idea notes contributed by Brad's class ( $M = 1.70$ ,  $SD = 1.06$ ,  $N = 10$ ),  $t(21) = 1.72$ ,  $p = 0.10$ ; again, the lack of significance is presumably due to the small number of CK notes. The high Inquiry scores for Hypothesis and Inquiry notes indicate students' CK contributions were reasoned and productive to the community's collective inquiry, within the limited capability to measure such terse notes.

### ***CK Version 1 Technology Limitations***

One technological limitation in the first iteration was that the IWB workspace became cluttered very quickly, as students contributed notes throughout the 90-minute inquiry activity. This echoed the pilot enactment’s finding of a heavy “orchestration load” (Dillenbourg et al., 2012) on teachers, who had to manage the classroom activity and monitoring incoming notes. Furthermore, the system did not support the categorization of Idea notes that were topically related. While the tablet interface allowed students to respond to a peer’s note using a build-on, it did not enable them to respond directly to a previous build-on in the note thread (i.e., build-on comments could not themselves be responded to; if a student wanted to respond to a build-on, she would have to add a second build-on to the original “parent” note). However, teachers and students did not find this to be problematic, since all build-ons appeared serially, and could be read naturally as a discussion thread. Finally, there was little or no pedagogical incentive for students to read peers’ notes and make conceptual connections (i.e. towards synthesizing knowledge on an individual level, and knowledge convergence on a community level). In essence, the limited complexity of the HelioRoom puzzle did not afford protracted arguments, warrants, or rebuttals. Hence, build-ons were somewhat incidental, occurring only if a student happened to have a specific reply to a note s/he was reading. Table 8 summarizes this iteration’s technological limitations.

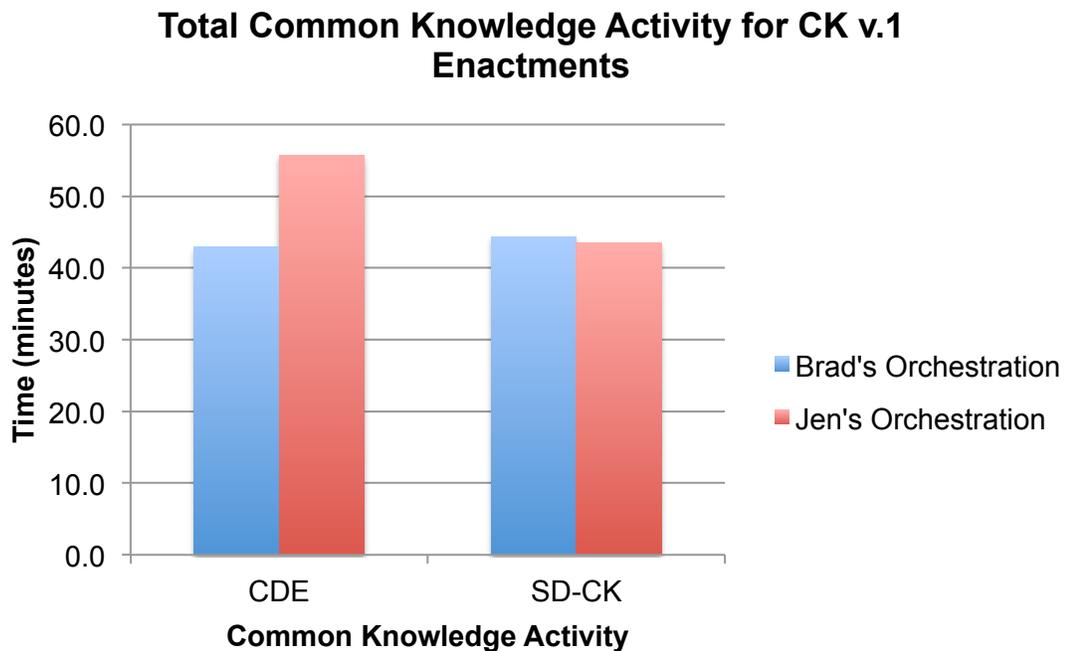
Table 8  
*Summary of Iteration 1 Technological Limitations*

	<b>Iteration 1 Limitations</b>
<b>Individual Tablet Interface</b>	Only 1 student could login from a tablet to the system at a time.
	Did not support categorization of topically-related notes.
	No incentive to read peers' notes and make conceptual connections to them.
	Provided a sense of inquiry productivity (i.e. note contributions), but not inquiry progress.
<b>Public</b>	Notes cluttered the workspace.

<b>IWB Interface</b>	Heavy orchestration load on teachers to monitor incoming notes and manage classroom concurrently.
	Heavy cognitive load on teachers to analyze and synthesize incoming notes (i.e. formative assessment of community's emergent state of knowledge).
	Did not support categorization of topically-related notes.
	Gave a sense of inquiry productivity, but not inquiry progress.

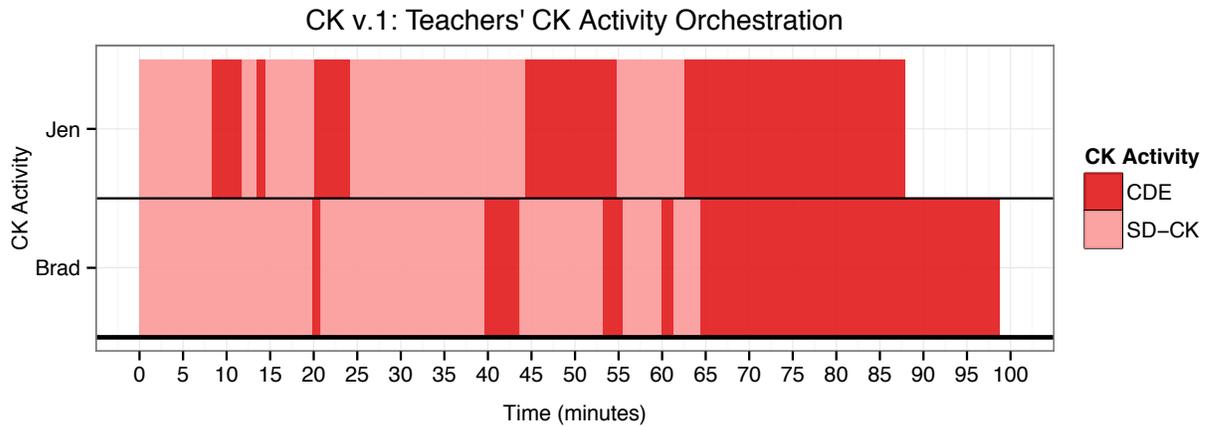
### **CK Version 1 Enactment: Activity Orchestration**

Video data of the enactments of iteration 1 were reviewed and coded in terms of the main focus of activity. Any teacher-guided community oral discussion about the inquiry activity at hand, involving at least 1 student speaker and lasting for at least 1 minute, was coded as a community discourse episode (“CDE”). CDEs often occurred within a “catch” phase of the session, but also occurred when the teacher interrupted the class during a “release” phase for a minute or two. Student-driven activities that involved Common Knowledge were coded as “SD-CK”. Figure 20 shows the amount of time spent on the CDE and SD-CK orchestration events, within a 90-minute session of HelioRoom explorations. As revealed in the graph, nearly the entire session comprised these two types of interactions, with 98 minutes for Brad (he spent some extra time during a break, thus eclipsing the 90 minutes) and 87 minutes for Jen.



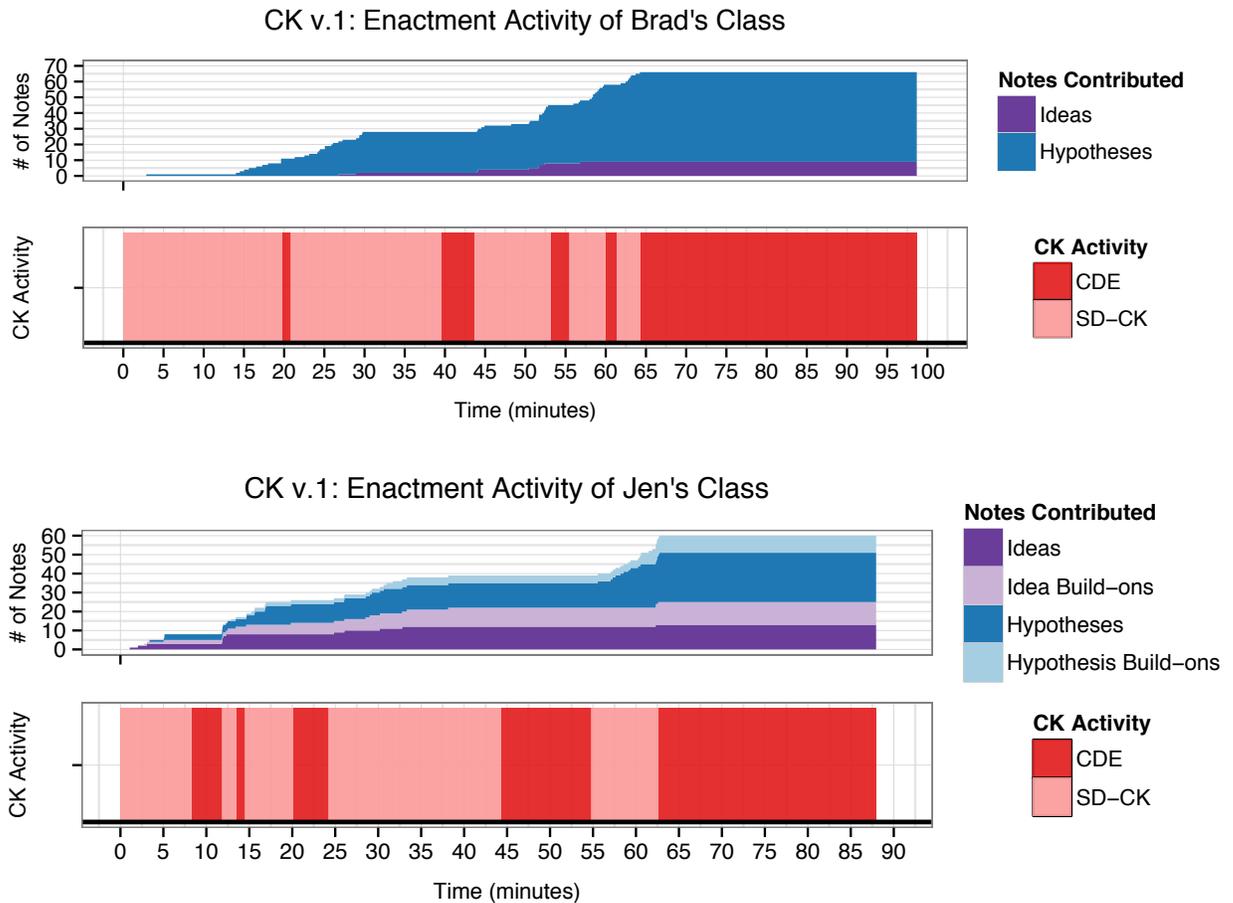
*Figure 20.* Total time spent on teacher-guided community discourse episodes (CDE) and student-driven activities involving Common Knowledge (SD-CK), in both teachers' classes, within a 90-minute session of HelioRoom explorations.

Video segments of all teacher-guided community discourse episodes (CDEs) were reviewed and coded for discourse topics and the inquiry objectives. Figure 21 shows the activity sequencing of each teacher's orchestration of inquiry activities involving Common Knowledge. Both teachers began with autonomous periods of students entering CK notes (in conjunction with HelioRoom observations), then utilized a Catch-and-Release orchestration pattern similar to that seen in the pilot enactments, with alternating teacher-directed and student-driven activities. Both teachers are also seen to end with substantive teacher-guided discussions, in Jen's case lasting more than 30 minutes.



*Figure 21.* Activity timeline of teacher-guided community discourse episodes (CDEs) and student-directed inquiry, involving Common Knowledge (SD-CK).

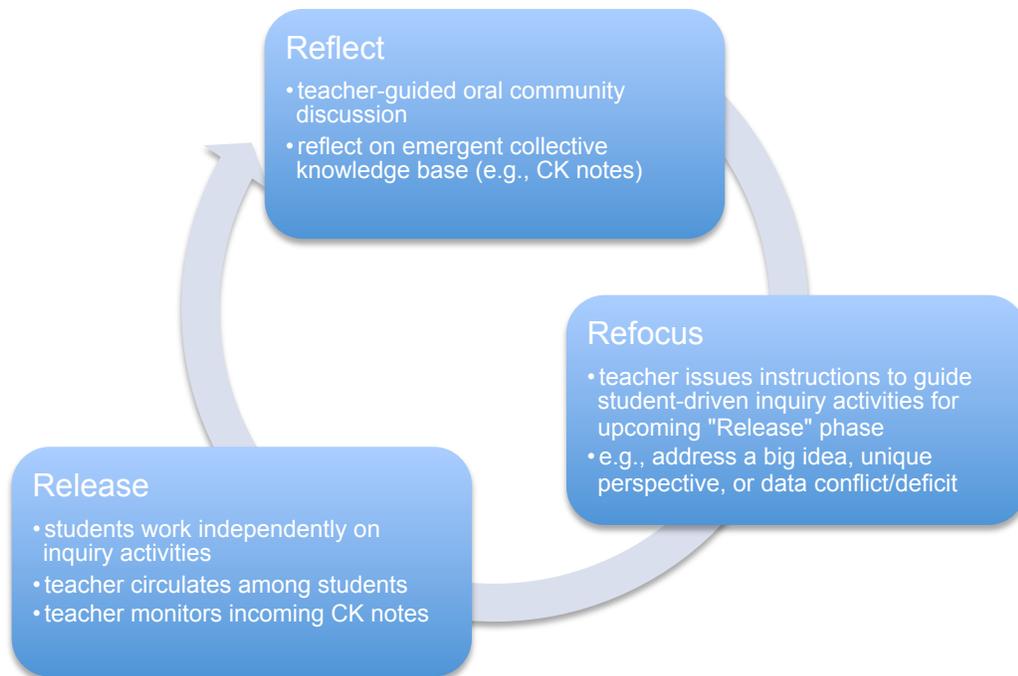
Qualitative examination of teachers' Catch-and-Release activity pattern revealed more detail of the Catch phase, as consisting of (1) guided *reflective* discussion, followed by (2) instructions to *refocus* the community's subsequent tasks or goals for inquiry. This pattern can be defined as *Reflect-Refocus-Release* (or "3R"), and offers a better description (i.e., than "Catch-and-Release") of teacher-guided oral discussions that occur when CK is in use. During the *Release* phase, teachers circulated among students to monitor their progress, probe their thinking, challenge any misconceptions, and respond to questions. Teachers would also periodically approach the IWB to monitor the emergent, collective knowledge on the IWB interface – reading notes, and occasionally dragging notes into topically meaningful clusters. Teacher-guided discourse episodes and student-driven (i.e., notes) activity can be aligned, temporally, revealing patterns of note contribution corresponding to discourse episodes (see Figure 22).



*Figure 22.* Enactment timeline for Brad’s and Jen’s orchestration of Common Knowledge activity. Bottom (pink and red) level in each graph: Jen’s orchestration sequencing of teacher-guided community discourse episodes (CDEs) and student-directed inquiry work periods, involving Common Knowledge (SD-CK). Top level in each graph: students’ note contribution activity, differentiated by note type.

Figure 22 illustrates that teachers guided their community towards productive courses of inquiry through rounds of *reflective* community discourse culminating in teachers’ instructions that *refocus* the community’s subsequent inquiry activity, whereupon students were *released* to pursue their inquiry trajectories – resulting in further note contributions to the collective knowledge base. New rounds of note contributions correlate directly with “Release” phases of student-driven Common Knowledge activity (“SD-CK” in each figure), which is not surprising, since notes were not meant to be contributed whilst teachers were engaging in discourse. The 3R cycle (Reflect-Refocus-Release – see Figure 23) figured prominently in teachers’ orchestration

of their enactment. As discussed in the next section, reflective discourse was pivotal in helping students develop awareness of their community's state of knowledge, achieve knowledge convergence, and receive guidance towards productive inquiry.



*Figure 23.* The 3R orchestration cycle: Reflect, Refocus, Release.

### ***CK Version 1 Activity Script Limitations***

Visualizations of the HelioRoom aggregate observations (i.e., the filterable table of combined observations) and CK hypotheses notes represented the community's knowledge, but there were no explicit steps or sequences in the activity script that would help the teacher or students employ those representations to make inquiry progress. Thus, the teacher was left to bear the load of guiding community analysis, synthesizing collective knowledge through community discussion, while also managing the pacing of activities, and orchestrating inquiry

(i.e., forming all the student groups and helping them to engage in the activities). Moreover, the script did not explicate that students should read their peers' notes and try to make conceptual connections, so that some students were not active in doing so, and the teacher had to try to encourage such connections.

### **CK Version 1 Enactment: Discourse Patterns**

To examine the discourse patterns that occurred during the use of CK in iteration one, I begin by characterizing each of the community discourse episodes (CDEs) in terms of the Refocusing goals that it sought to achieve. Table 9 summarizes Brad's and Jen's refocusing instructions corresponding with each of their CDEs. This qualitative description offers insights about the purpose of the 3R cycles, and can be used to understand how teachers guide a community towards productive inquiry activity. Both class sessions had 5 discourse events (i.e., CDEs) – the final serving as a culminating discussion, and hence not including any refocusing instruction. In addition, Jen's third CDE was a form of check-and-continue discussion, and did not include any refocusing segment, with students just urged to carry-on in their existing focus (i.e., collecting planet observations).

Table 9  
*Teachers' Refocusing Instructions Issued During Community Discourse Episodes*

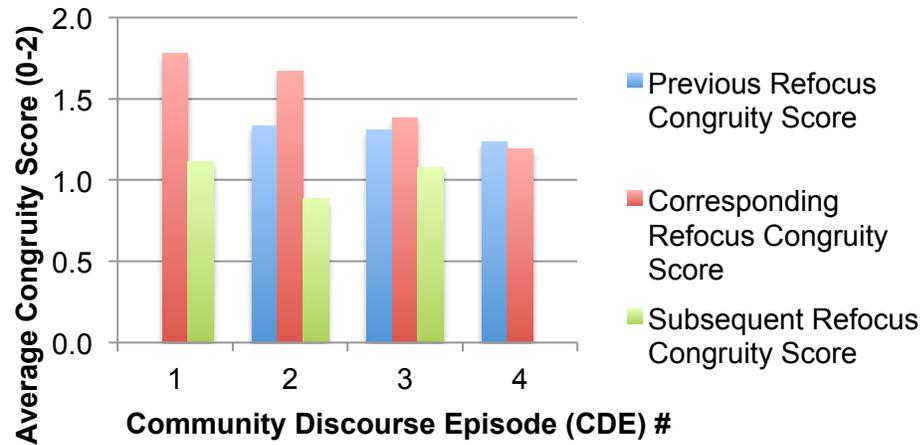
<b>Teacher</b>	<b>CDE #</b>	<b>Teacher's Refocus Instruction</b>
Brad	1	Start formulating hypotheses.
Brad	2	Add more hypotheses, with more detailed evidence.
Brad	3	Contribute evidence-based hypotheses about Green, Yellow, and Orange planets.
Brad	4	Write evidence (for Hypotheses notes) more clearly and to include more detail, to help the community sort out conflicts/disagreements in hypotheses.
Brad	5	<None>
Jen	1	Make more careful observations, be more specific, consider more (disc) colours.

Jen	2	When contributing a note, differentiate between "Hypothesis" notes (are in colour - is evidence, using a lot of logic, based on observation) and "Idea/Comment" note (are white). Don't submit a hypothesis using an "Idea/Comment" note.
Jen	3	Carry on, continue with the same goals in mind.
Jen	4	Formulate hypotheses for: Mars, Jupiter, Saturn, Uranus, Neptune, Pluto, in the next 10 minutes.
Jen	5	<None>

*Note.* CDE numbers refer to CDE mappings in Figure 22.

To see if the refocusing instructions had an impact on student contributions, all student notes were scored for Congruity with the teacher's Refocus Instructions, on a simple 3-point scale (2 = congruous with the prompt; 1 = somewhat congruous; 0 = not congruous). Every note that was contributed in the time following a CDE's "Refocusing" instruction was first scored for its congruity with its "Corresponding Refocusing Instruction", as well as its congruity with the "Previous Refocusing Instruction" (i.e., of the preceding CDE) as well as with the "Subsequent Refocusing Instruction" (i.e., of the next CDE that had yet to come). 20% of all note types from both classes were independently scored for Congruity with teacher's corresponding refocus instructions by this study's second rater and me. Inter-rater agreement was 82.6%, with Cohen's Kappa = 0.66. Inter-rater disagreements on Congruity scoring were related to the rater's limited understanding of the community's collective inquiry progress throughout the session. Figure 24 summarizes the congruity of students' notes with teachers' refocusing instructions, showing that students in both teachers' classrooms shifted the focus of their note contributions in response to the teacher's Corresponding Refocusing Instruction.

### CK v.1: Congruity of CK Notes with Jen's Refocusing Instructions



### CK v.1: Congruity of CK Notes with Brad's Refocusing Instructions

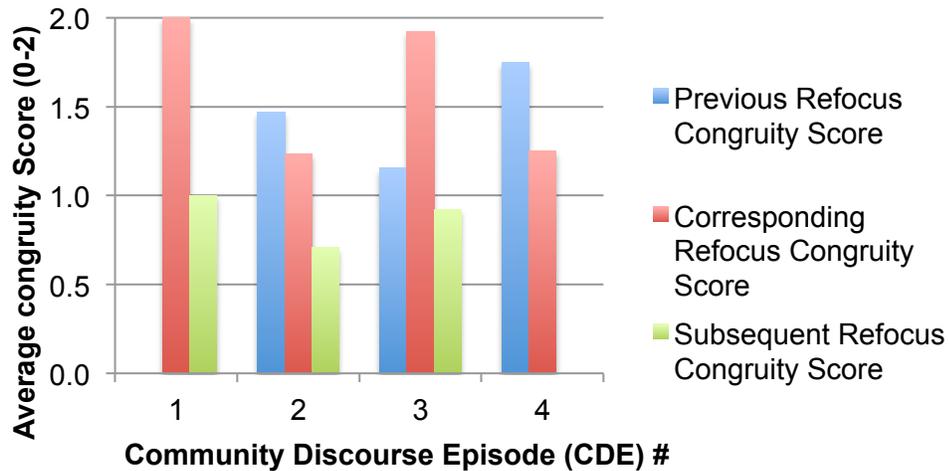


Figure 24. Average Previous Refocus, Corresponding Refocus, and Subsequent Refocus Congruity Scores of CK notes for Jen’s and Brad’s classes.

Figure 24 confirms that student notes were more congruous with the immediately relevant (i.e. corresponding) refocusing prompt, presumably because it contained instructions and orientations. Though in some rounds of note contribution, notes seemed to be more

congruous with Previous Refocus prompts. It is not surprising that teachers' successive refocusing instructions would follow the same trajectory with increasingly refined breadth, given that the HelioRoom inquiry was only a 90-minute activity, and paired *t*-test comparisons reflect this. For Brad's class, a paired *t*-test was done to compare the mean Congruity Score of notes against their Corresponding (i.e., appropriate) Refocus Instruction with the mean Congruity Score of the same notes against the Previous Refocus Instruction, and found no significant difference with  $t(37) = 0.44, p = 0.33$ . However, a paired *t*-test confirms the mean Congruity Score of notes against their Corresponding Refocus Instruction is significantly higher than the mean Congruity Score of the same notes against the subsequent (i.e.,  $n + 1$ ) CDE, with  $t(46) = 6.75, p < 0.001$ . For Jen's class, similar tests showed that Corresponding Congruity Scores are not significantly higher than the mean Previous Congruity Scores, with  $t(42) = 0.72, p = 0.24$ , but are significant for Subsequent Congruity Scores with  $t(30) = 2.73, p = 0.01$ .

To better understand the "reflection" portions of the CDE the discussion, I examined each CDE in terms of the *social participation structures* (Erickson, 1982b) to determine teachers' discourse "orientations" within each of the CDE. Such orientations characterized how the teacher socially positioned his or her utterances in relation to the community, such as through asking a rhetorical question, or a direct question to a particular student, or an open question for the whole class, or perhaps in making a declarative statement not intended for any response. In reviewing video clips of the discourse events, the following four orientations were distinguishable, often occurring within the same CDE, with teachers moving fluidly between them with rhetorical purpose:

- (1) Teacher Reflection (TR) where the teacher shares a personal inquiry reflection;

- (2) Individual Student Reflection (IR), where a specific student or working group is asked some inquiry reflection question;
- (3) Whole Class Reflection (CR) where the teacher invites the whole class to reflect on some inquiry question; and
- (4) Whole Class Instruction (CI), where the teacher gives instructional comments to the class as a whole.

These orientations will form the basis of my analysis of discourse iteration 2, to understand how teachers use the student ideas captured in CK notes to orchestrate productive inquiry discourse during the Reflect phase of the 3R cycle, to support and investigate how teachers guide the classroom community through inquiry progressions. Iteration 1 of CK was useful in revealing a more nuanced 3R cycle for catch-and-release activity pattern. It also showed that teachers' refocusing instructions had a direct impact on the focus of student notes, and identified four orientations for teacher-guided discourse events.

### **CK Version 1 Implications: Design Goals for CK Version 2**

The activity design for iteration 1, where CK was integrated within the HelioRoom simulation puzzle (and the CK technologies of the tablet and IWB tools were integrated with the HelioRoom planet observation and IWB summary views, respectively) limited the overall duration and scope of discussions. Although students could build-on to a note thread, they could not respond directly to another build-on in the thread. Moreover, the conceptual depth of discussions was limited to matters concerned with the HelioRoom puzzle, and hence could not progress much further beyond topics of the form: "...*brown is the fastest planet, so it must be the Mars which is the closest planet to the sun...*". Visual representations of aggregate observational

data and evidence-based hypotheses and ideas were designed with conceptual organization in mind, to help teachers monitor and synthesize the community’s ideas and facilitate inquiry discussions that motivated reflection and progress. However, there were limits in the kind of “knowledge work” that could be done by students and teachers on the CK notes. They could not be topically categorized by the community, nor filtered in any way. Hence, the volume of student-contributed notes quickly cluttered the IWB interface’s workspace, and there was no visual sense of progression that could be discerned by participants (i.e. beyond increased note volume). Hence, the enactment analyses of CK iteration 1 revealed the following redesign goals for the second iteration (see Table 10).

Table 10

*Limitations of Iteration 1, and Corresponding Redesign Goals for Iteration 2*

	<b>Iteration 1 Limitations</b>	<b>Technology Redesign Goals for Iteration 2</b>
<b>Individual Tablet Interface</b>	Only 1 student could login from a tablet to the system at a time.	Allow flexible student groupings/logins.
	Did not support categorization of topically-related notes.	Enable notes to be tagged.
	No incentive to read peers' notes and make conceptual connections to them.	Provide technological reason/incentive to read peers' notes and make conceptual connections to them.
	Provided a sense of inquiry productivity (i.e. note contributions), but not inquiry progress.	Provide a sense of inquiry progress.
<b>Public IWB Interface</b>	Notes cluttered the workspace.	Offer a way to de-clutter the workspace, perhaps with note filters.
	Heavy orchestration load on teachers to monitor incoming notes and manage classroom concurrently.	Support classroom management tasks such as: helping the teacher get and maintain student attention, manage flexible student groupings for different activities.
	Heavy cognitive load on teachers to analyze and synthesize incoming notes (i.e. formative assessment of community's emergent state of	Visibly connect topically-related notes to indicate the quantity of related notes, and their degree of relatedness.

	knowledge).	
	Did not support categorization of topically-related notes.	Enable notes to be tagged.
	Gave a sense of inquiry productivity, but not inquiry progress.	Provide a sense of inquiry progress.

### **CK Version 2: WallCology**

The second iteration of Common Knowledge was again integrated into a broader suite of software applications that were used by students and teachers on tablet computers and interactive whiteboards (IWBs) to investigate an Embedded Phenomenon simulation as it ran uninterrupted in their classroom for 9 weeks (Moher & Slotta, 2012). This time, the class communities were engaged in a more substantive 9-week biodiversity inquiry, as students contributed observational data to a collective knowledge base about WallCology, a simulated ecology of flora and fauna ostensibly “living” in their classroom walls (see Chapter 3, Figure 8). Students were tasked with determining each species’ life cycle, environmental and food preferences, and the ecosystem’s food web, by entering observations and notes about the habitats within each of their four classroom walls (i.e., one Wallscope monitor was situated on each classroom wall). The activity script included several distinct phases, each of which was scaffolded by specific tablet applications and configurations of CK: habitat observations, organism observations, inter-species food web (energy) relationships, population counts, and investigations (i.e., the distinct tabs across the top of the tablet interface, shown in Figure 25).

### **CK Version 2: Design Analysis**

This second iteration of Common Knowledge was more “open” with respect to the topic and purpose of notes, with no pre-specified discussion topics and a less scripted space of

possible ideas than seen in iteration 1. The next four sub-sections will present the design of CK version 2, in terms of the technology features, the activity script, and our expectations of discourse patterns.

### **CK Version 2: Responding to Design Recommendations from CK Version 1**

Our design of CK iteration 2 was again guided by the general goals of enabling students to contribute their ideas to a collective knowledge base, access their peers' ideas, and visualize the community's ideas. We maintained the approach of a tablet interface for students working individually or in pairs (i.e. for note contributions and other "knowledge work"), and a separate IWB interface for public use (i.e. for teacher-guided community knowledge work, or students working in small groups at the board). On each of these two applications (tablet and IWB) we made design improvements with the aim of extending the CK functionality and responding to limitations or opportunities identified in iteration one. Specific responses to re-design goals are summarized in Table 11. Again, this work was conducted by a team of 10 people, including four researchers (two senior investigators, one PhD student, and one Masters student), four technology developers, and 2 teachers. The design and investigation of CK was one component of the broader research agenda relating to knowledge communities and embedded phenomena (Fong, Pascual-Leone, et al., 2012; J.D. Slotta et al., 2011).

Table 11  
*Iteration 2 Technology Features that Respond to Redesign Goals*

	<b>Technology Redesign Goals for CK v.2</b>	<b>CK v.2 Response to Redesign Goals</b>
<b>Individual Tablet Interface</b>	Allow flexible student groupings/logins.	Multiple students able to login to 1 tablet, to contribute CK notes as co-authors.
	Enable notes to be tagged.	List of pre-seeded tags available during note creation.
	Provide technological reason/incentive to read peers' notes and make conceptual connections to	No technological design response. Reliance on curriculum design and teacher scaffolding, to promote

	them.	peer-to-peer conceptual connections.
	Provide a sense of inquiry progress.	Reliance on WallCology app and curriculum design to provide sense of inquiry progress. Continue to provide a sense of inquiry productivity (i.e. visualize quantity of note contributions).
<b>Public IWB Interface</b>	Offer a way to de-clutter the workspace, perhaps with note filters.	Dual-functioning tags not only semantically categorize notes, but also function as note filters on the IWB.
	Support classroom management tasks such as: helping the teacher get and maintain student attention, manage flexible student groupings for different activities.	No technological design response. Reliance on teachers' classroom management skills, curriculum design and teacher scaffolding; to get and maintain student attention, and to manage student groupings for different activities.
	Visibly connect topically-related notes in such a way that would also indicate the quantity of related notes, and their degree of relatedness.	Tags, functioning as note filters can display topically-related notes of multiple selected tags.
	Enable notes to be tagged.	Note may only be tagged at the time of note creation.
	Provide a sense of inquiry progress.	Reliance on WallCology app (i.e. inquiry topic tabs) and curriculum design to provide sense of inquiry progress. Continue to provide a sense of inquiry productivity (i.e. visualize quantity of note contributions).

### **CK Version 2 Design: Technology Features**

One new feature of the CK tablet was a set of note tags that allowed students to select the type of note: questions, observations, theories, and other ideas (see Figure 25). These science inquiry process tags were intended to help students reflect on inquiry and develop metacognitive awareness of the specific forms of inquiry in which they were engaging. During note creation, students could also “tag” their contributions from a list of keywords for science content (e.g., “Temperature”, “Light”, “Organism”). The available tag list varied according to which inquiry

phase the student was currently working on within the WallCology curriculum, such that students only encountered relevant tags for the topic of inquiry at hand (discussed further in next section, Activity Script). Table 12 lists the keyword tags that were provided to students in the various WallCology inquiry phases.

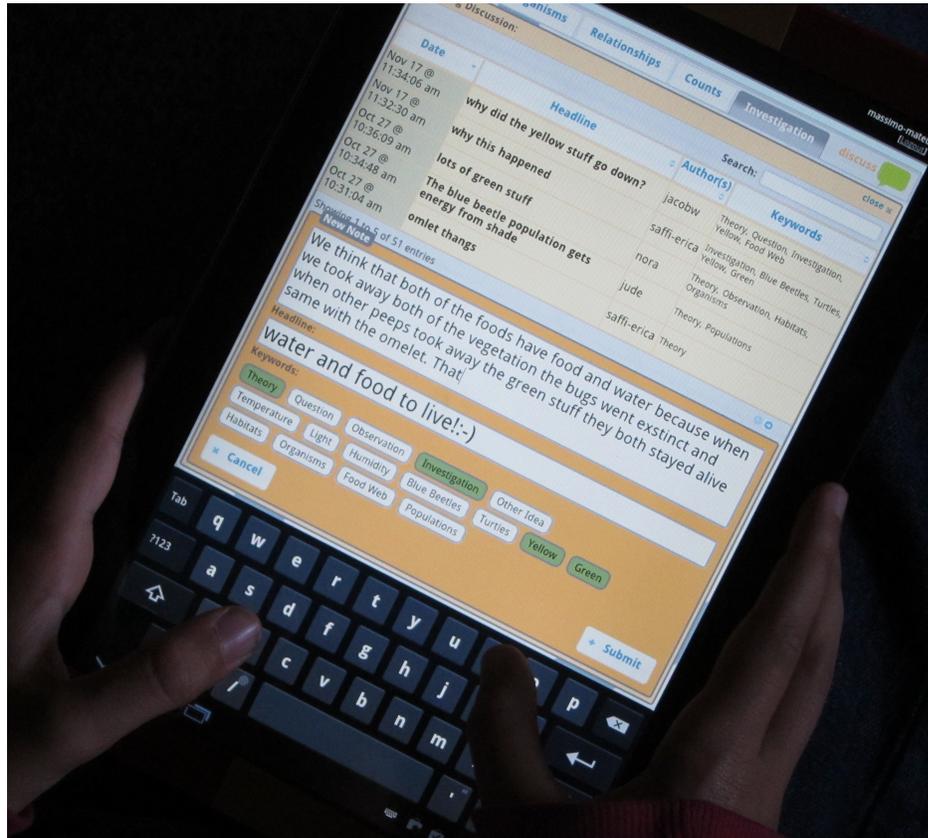


Figure 25. Iteration 2 tablet interface. WallCology inquiry topic tabs line the top of the screen. Top half of the screen lists the community’s notes. To read a note, students press its “Headline”, and the note opens in an overlay. The student shown here is composing a new note, seen in the bottom half of the screen, which includes a “Note” text field, a “Headline” text field, and several optional tags relevant to the “Investigations” topic of inquiry in the WallCology app. Author-selected tags are highlighted in green.

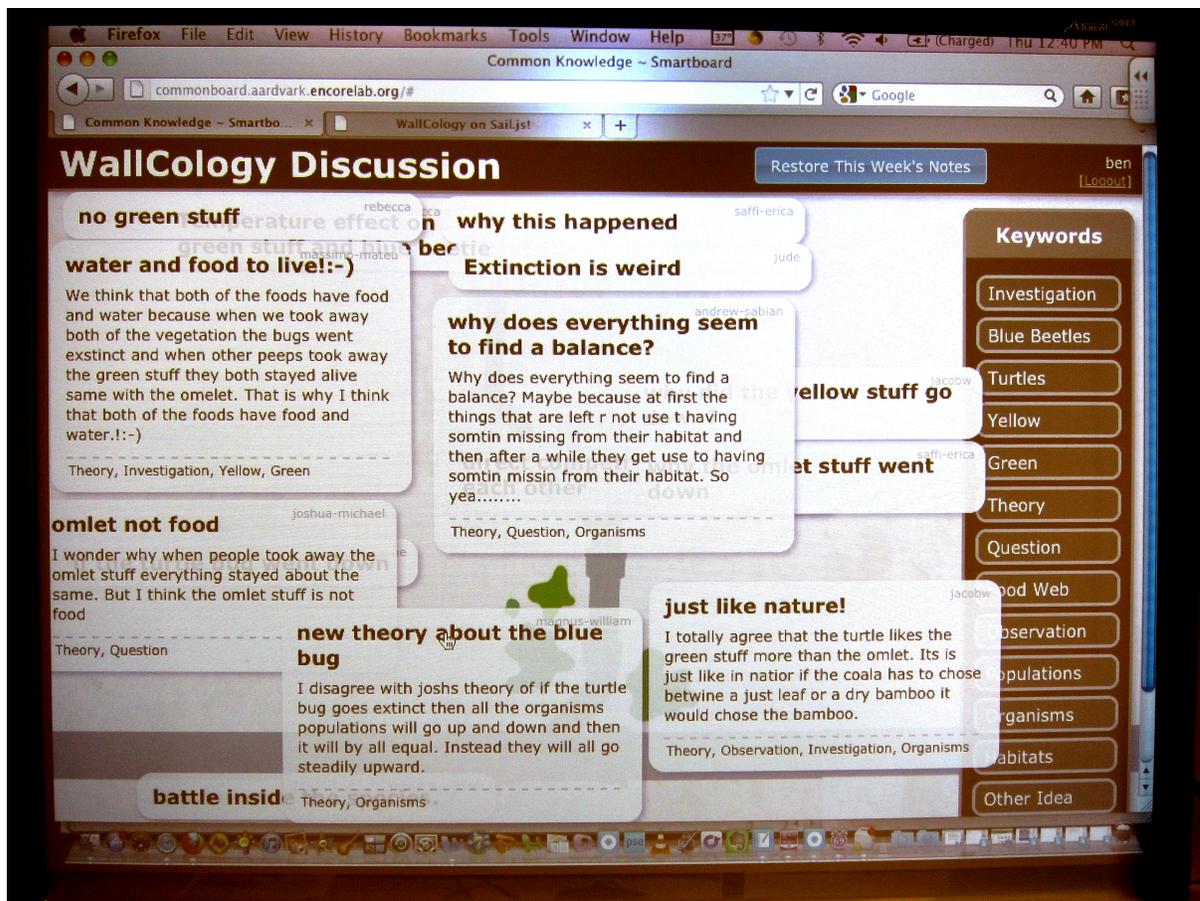
Table 12  
*Keyword Tags Provided to Students in Various WallCology Inquiry Topics*

Keywords	WallCology Inquiry Phase					
	Habitats	Organisms	Life Cycles	Relation-ship	Counts	Investiga-tions

<b>Science Process</b>	Theory	✓	✓	✓	✓	✓	✓
	Question	✓	✓	✓	✓	✓	✓
	Observation	✓	✓	✓	✓	✓	✓
	Other Idea	✓	✓	✓	✓	✓	✓
<b>WallCology Content</b>	Morphology		✓	✓			
	Behaviour		✓	✓			
	Suggestion for Food Web				✓		
	Environmental Conditions	✓				✓	
	Structural Features	✓				✓	
	Temperature						✓
	Light						✓
	Humidity						✓
	(5 organism names, decided by the knowledge community)						✓
<b>WallCology Inquiry</b>	Habitats	✓	✓	✓	✓	✓	✓
	Organisms	✓	✓	✓	✓	✓	✓
	Life Cycles		✓	✓			
	Food Web	✓	✓	✓	✓	✓	✓
	Populations					✓	✓
	Investigation	✓	✓	✓	✓	✓	✓

As in the first iteration of Common Knowledge, all student-contributed notes appeared dynamically on all other student tablets as well as on the classroom's IWB, where the notes' headlines appeared as movable white text boxes as soon as they were submitted to the CK knowledge base (see Figure 26). Teachers could tap the topic headline to open the note for

reading (a new feature from version 1, where all notes appeared in static, open format) and drag notes into spontaneously identified topic clusters. Tapping the note again would close it into the headline note icon. Tags appeared on the right side of the IWB, as individual buttons, with the primary purpose of enabling teachers to filter notes while guiding discussions as well as managing screen real estate. Pressing one or more tags in this panel served to filter the display, so as to show only notes associated with those tags. This capability of filtering notes allowed teachers to swiftly display topic-relevant notes within the context of oral community discussions.



*Figure 26.* Iteration 2 public IWB interface. A note's headline instantaneously appears as a movable white text box, upon submission to the community's collective knowledge base. Pressing the headline opens the note. A note's tags appear at the bottom of the note. All notes may be dragged by the teacher or students into topic clusters. The darker panel at the right is a list of tags, which serve as note filters. Pressing one or more tag filters displays only notes associated with those tags. If no tag filters are selected (as seen here), all notes appear.

## **CK Version 2 Design: Activity Script**

The WallCology curriculum unit consisted of several inquiry phases, designed to be completed by a classroom community in a sequence, such that each phase depended on ideas from the previous: habitats, organisms, life cycles of organisms, interspecies food web (energy) relationships, population counts, and simulation investigations in which environmental factors and species populations could be manipulated by learners. Within each phase, students were scaffolded by a carefully designed technology environment, which was accessed through separate tabs in the WallCology app (see Figure 25). In each phase, Common Knowledge was continuously available as another tab, including tags that were specific to the inquiry phase at hand.

One open question was concerned with how teachers would progress from one stage of inquiry to the next (e.g., the move from inquiring about organism life cycles to understanding food webs). We expected that teachers would attend to students' engagement and progress on one inquiry phase until they felt satisfied with the content of CK notes and oral discussions, then hold discussions that motivated the move to the next phase of inquiry. This use of the technology to help scaffold and reify the inquiry progression was an important design feature of WallCology, and was seen as intrinsic to the design of CK iteration 2 (i.e., being linked to a progression of inquiry activities).

Prior enactments of CK had indicated a cyclical "Catch-and-Release" activity pattern of orchestration. Analysis of activity in iteration 1 further examined the "Catch" phase to find a blend of "Reflect and Refocus" discussions (the 3R cycle). The teachers had shown impressive capabilities in such patterns of activity, leaving students to work on notes and observations while they interacted with small groups, and monitored the content of incoming CK notes on the IWB.

Hence, we anticipated such activity patterns again for this iteration, and hoped that the presence of tags and distinct inquiry phases would support teacher-guided discussions.

### **CK Version 2 Design: Expected Discourse Patterns**

Analysis of the previous Common Knowledge enactment had revealed four orientations of teachers' discourse patterns: Teacher sharing a personal inquiry reflections (TR); teacher inviting an individual student or student work group to reflect on an inquiry question (IR); teacher inviting the community to reflect on an inquiry question (CR); and teacher giving instructional comments to the community (CI). In iteration two, we expected to see these orientations again, with greater level of depth in discussions, reflecting the more substantive inquiry domain of WallCology (i.e., a 9-week investigation of digital ecologies, as opposed to a 90-minute solution of the HelioRoom puzzle). We anticipated that CK discussions would offer teachers one means of helping the class progress within an inquiry phase, and ultimately to motivate engagement in the next phase. Ultimately, our goal for CK is to support teachers in using representations of community knowledge (e.g., the CK IWB, or other WallCology collective representations) to orchestrate discourse that engages and advances students in inquiry.

O'Connor and Michaels (1996) analyzed "Revoicing" – the oral or written reuttering of student contributions – which is one means by which teachers can make use of student ideas in advancing the class inquiry. This work argued that, through revoicing, a teacher may: (1) credit a student for their contribution while clarifying it, (2) "animate" students into intellectual roles thereby socializing them as legitimate participants of intellectual practices (i.e. speaker casts another speaker into a role through discourse from one speaker to another, or through one speaker's discourse about another person), (3) laminate or fuse their own phrasing or information onto the student's contribution while rebroadcasting the student's reasoning to the entire class –

hence animating the student as a speaker in a larger public sphere, and/or (4) bring students' ideas into contact with each other. Traditional IRF (Initiate Response Follow-up) discourse sequences (i.e. teacher initiates a verbal exchange, student responds, teacher evaluates, then follows-up on a student's contribution) are limited. Revoicing, however, allows for more meaningful exploration of the inquiry topic at hand, and creates the possibility for students to evaluate or follow-up on their teacher's revoicing moves. Students are given more agency as active learners in such discourse constructs, flattening the traditional hierarchical relationships.

Given the substantive nature of WallCology investigations, we anticipated that teachers would employ revoicing and other techniques of summarizing students' individual and collective progress, to guide community reflections and help motivate inquiry progress. As this version of CK was designed to work in parallel with the various WallCology inquiry tools, our goal was for teachers to adapt CK to each inquiry phase, using it to reflect on progress and advance to the next inquiry phase. Analysis of the enactment, presented next, will examine the details of how CK was used for these purposes, including a finer grained description of teacher discourse moves.

### **CK Version 2: Enactment Analysis**

Common Knowledge was available to teachers and students throughout the 9-week WallCology inquiry unit, but not required to be used in every class session. There were times when students and teachers felt that adding CK notes could advance the inquiry, and other times when the WallCology applications alone were sufficient (i.e., by asking students to add CK notes, it may have increased the complexity level for all participants). It was left largely to the teacher's discretion when they would encourage the use of CK, as well as when and what forms

of discussion should be included. Table 13 summarizes both Brad’s and Jen’s WallCology and Common Knowledge enactment time over the 9-week WallCology inquiry unit.

Table 13  
*Teachers’ WallCology and CK Enactment Time Over the 9-week WallCology Inquiry Unit*

	<b># of WallCology Sessions Enacted</b>	<b>Total WallCology Instructional Time (Hours)</b>	<b># of WallCology Sessions Involving CK Use</b>	<b>Total CK Time (Hours)</b>
<b>Brad</b>	17	16.35	10	7.62
<b>Jen</b>	16	19.00	7	9.33

In sessions involving the use of Common Knowledge, teachers either: (1) directed students to use CK during an independent work period (i.e., during the “Release” phase of the 3R cycle), or (2) referred to at least one CK note during an episode of teacher-guided community discourse, or (3) a combination of both. Two enactment sessions from each teacher were chosen for analysis of activity orchestration and discourse patterns, based on the richness of CK-driven oral community discourse within those sessions.

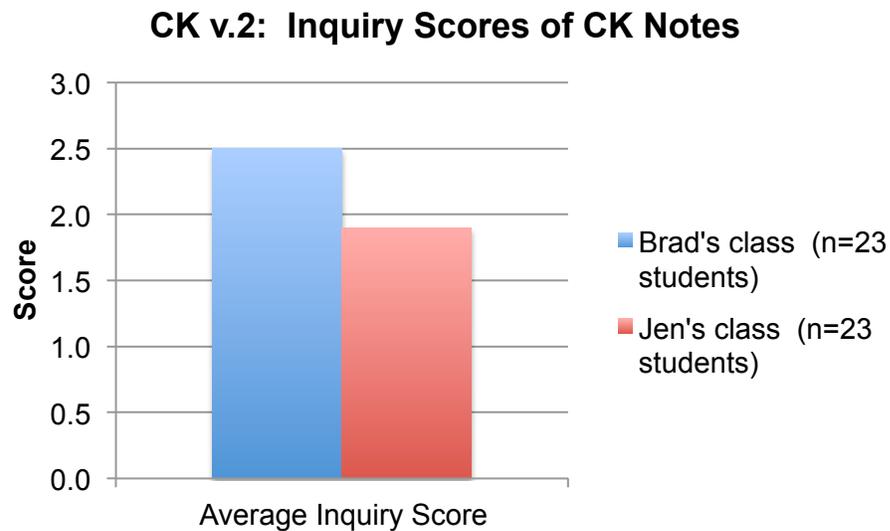
### **CK Version 2 Enactment: Technology Outcomes**

In iteration 2, students continued to use the CK tablet interface as a means of adding notes, and to tag notes with relevant semantic features. By the end of the 9-week WallCology unit, students in Brad’s class had contributed 171 Common Knowledge notes, with an average Inquiry score of 2.5, and an average of 2.0 tags per note. Jen’s class was quite different in their pattern of use, contributing only 85 notes, with an average Inquiry score of 2.2, but an average of three tags per note. A note’s Inquiry score was guided by a 4-point rubric inspired by the knowledge integration construct (Lee & Liu, 2010; Liu et al., 2008 - see Table 14), that assessed (1) the note’s productivity to the collective inquiry and (2) how well-justified the ideas were.

Table 14  
*Inquiry Scoring Rubric for Iteration 2 Common Knowledge Notes*

<b>Inquiry Score: Common Knowledge Notes</b>		
<p><i>Goal:</i> Well-justified, productive ideas that contribute to the collective inquiry.  <i>“Productive”:</i> contributes new and helpful information, testable ideas, suggestions of different inquiry approaches, acknowledgement of knowledge gaps  <i>“Well-justified”:</i> the idea/theory is supported by primary/observational data, reference to knowledge artifacts in the collective knowledge base (e.g., another Common Knowledge note), or secondary data</p>		
<b>Score</b>	<b>Definition</b>	<b>Example</b>
3	Productive and well-justified.	<i>I think that the turtle bugs may eat the shrimp things. Have seen the shrimp things go under the turtle thing and then disaper</i>
2	Productive but not well-justified, OR Well-justified but unproductive.	<i>I saw the blue beetle eating the yellow stuff and that makes the units go down. But after a while the yellow stuff grew again.</i>
1	Unproductive and not well-justified.	<i>I think that the omlet things look a bit like bird poop</i>
0	Off-topic, unrelated to the inquiry task at hand, or empty note.	<i>Olah amigos!!</i>

20% of notes contributed by were independently scored against this rubric (Table 14), by this study’s second rater and me. Inter-rater agreement was 88.9%, with Cohen’s Kappa = 0.61. Inter-rater disagreements were related to the rater’s limited understanding of the broader inquiry context in which a given CK note was composed. Figure 27 compares the average Inquiry scores for both classes. However, a two-sample *t*-test comparison of the mean Inquiry score of CK notes contributed by Brad’s class ( $M = 2.46$ ,  $SD = 0.52$ ,  $N = 171$ ) revealed it was significantly higher than the mean Inquiry score of CK notes contributed by Jen’s class ( $M = 2.24$ ,  $SD = 0.70$ ,  $N = 85$ ) with  $t(254) = 2.83$ , and two-tailed  $p = 0.005$ .



*Figure 27.* The average Inquiry scores for both class' Common Knowledge notes, contributed over the 9-week WallCology inquiry unit. Brad's class contributed a total of 171 notes, while Jen's class contributed 85 notes.

Teachers continued to use the public IWB interface of Common Knowledge as a grounding reference as they guided oral community discussions. Many occasions were observed where teachers employed the tag system to filter the notes, in order to address specific content themes, WallCology inquiry phases, or science processes; during the reflection discussions. They also sorted notes on the IWB, dragging them into topic clusters, and both teachers engaged students in sorting new notes into relevant topics. Students were also observed to use the large public representation of the knowledge base on the IWB as a grounding reference for their small group work.

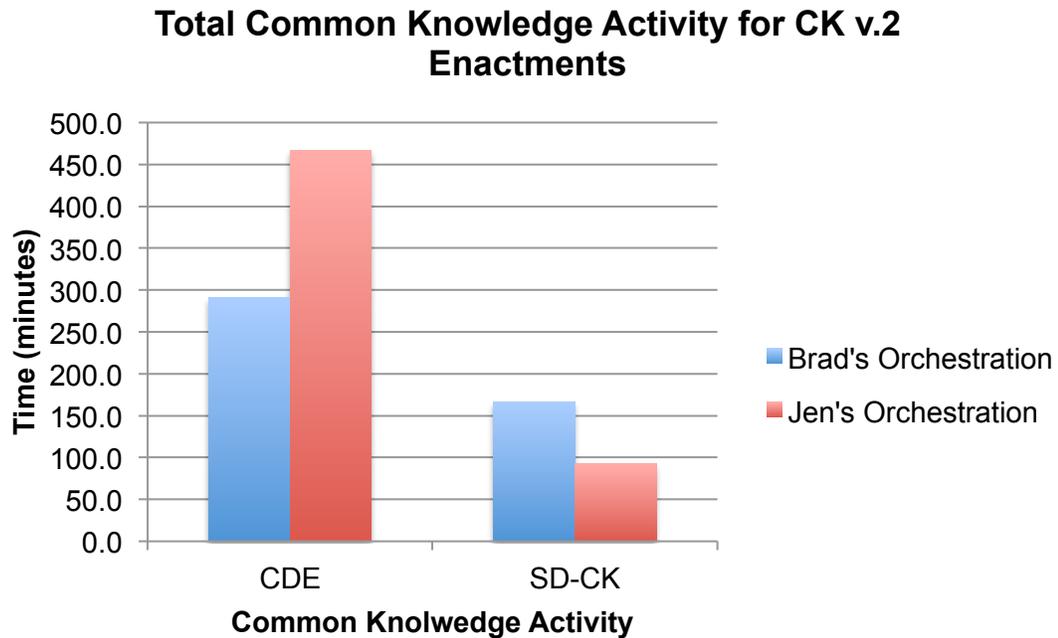
### ***CK Version 2: Technology Limitations***

Because of problems in the technical development, students were unable to respond directly (i.e., build-on) to their peers' notes. However, as in Brad's class during iteration one (where responses to notes were available, but Brad had forgotten to tell the students), students

did occasionally find an alternative means of directly responding, typically with the note title, (e.g., “I’m adding to Esme and Cleo’s theory about...”; or “I agree with Andrew and Sabian because...”, “I disagree with Josh’s theory...”, “I’m adding on to Simone’s note...”, and “Building on to Jacob’s investigation...”). Unfortunately, these notes were not represented as being connected to their targeted initiating note, so these note interactions and conceptual connections were not visually obvious to the community. This speaks again to the value of enabling threaded responses to student notes, allowing students to engage in peer-to-peer note interactions as part of their knowledge co-construction process. We had intended for this functionality, but because of some other needed features, and the spectrum of WallCology applications (all built by the same technology team, with limited human resources), the threaded annotation feature had to be suspended for this iteration, and listed as an important design target for the next iteration.

### **CK Version 2 Enactment: Activity Orchestration**

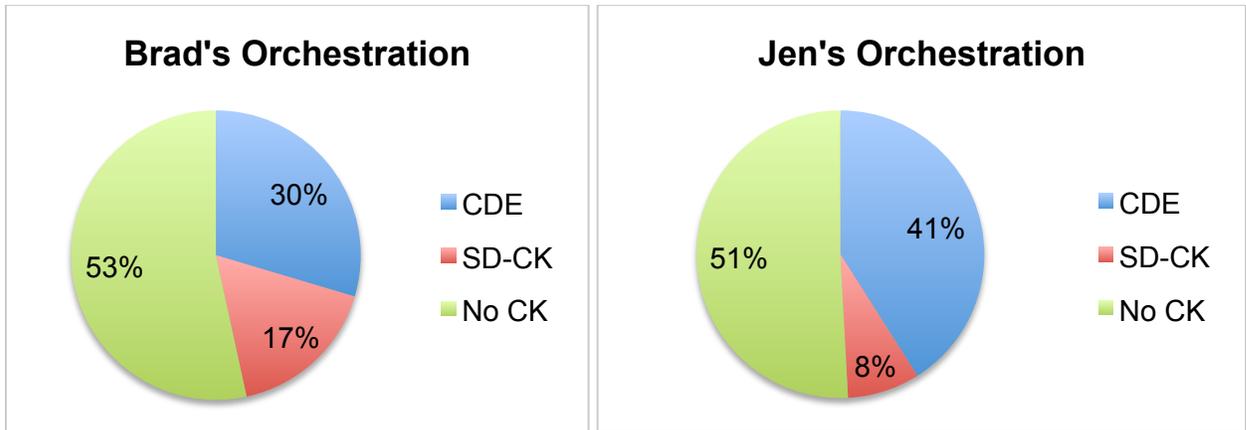
Video data of all class sessions was first coded very coarsely, for teacher-directed (TD) and student-driven (SD) inquiry activity involving CK. Within teacher-directed activities involving CK, teacher-guided community discourse episodes (CDE) were then coded, as in Iteration 1. Analyses of Iteration 2 enactments will focus on the teacher-guided community discourse episodes involving CK, with some consideration of student-driven activities in relation to their sequencing with CDEs. Figure 28 compares the amount of time each teacher orchestrated community discourse episodes involving the use of CK (CDE), and the amount of time they gave their students to do independent or small group work using the CK environment (SD-CK). Brad’s students spend less time engaged in community discourse, and more time working within the CK environment, whereas the opposite was true for Jen’s students.



*Figure 28.* A comparison of teachers' enactment time throughout the 9-week WallCology unit, as allocated to community discourse episodes involving the use of Common Knowledge (CDE), and student-driven work in the Common Knowledge environment (SD-CK). Brad orchestrated a total of 457.1 minutes of CK activity, and Jen orchestrated a total of 559.9 minutes of CK activity.

As shown in Figure 29, teachers spent approximately half of the overall instructional time using Common Knowledge – either as a grounding reference during teacher-guided community discussions (CDE), or having their students use it to share their thinking during student-driven inquiry work periods (SD-CK). Approximately 50% of all class time was spent in the absence of CK, consisting mostly of student inquiry using other WallCology inquiry tools, and teacher-guided discourse that did not reference CK notes (i.e., teachers used the WallCology IWB representations). It is interesting to note that both teachers spent more time guiding community discussions spurred by Common Knowledge notes than they allowed for their students to independently contribute or read CK notes. This reinforces the importance of teacher-guided discourse, as both of these teachers were highly experienced with Knowledge Building and

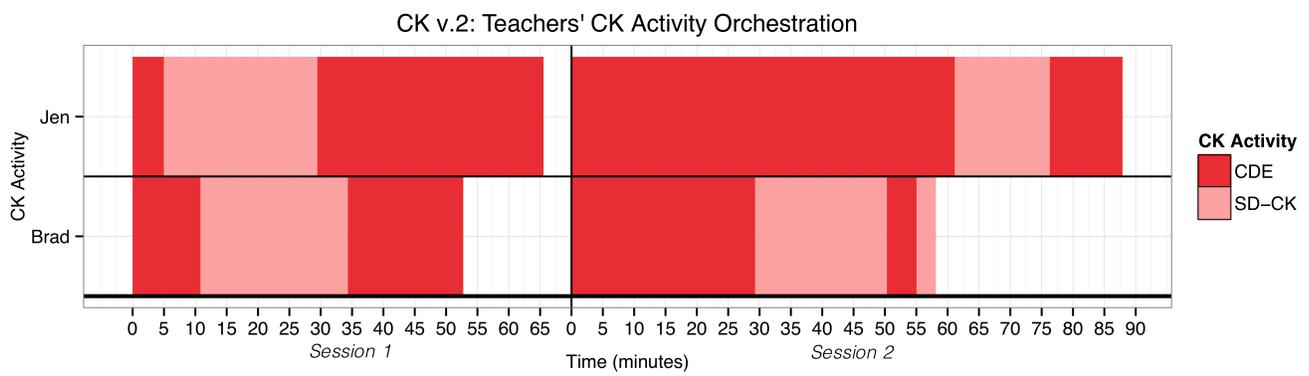
inquiry pedagogy, and both were able to use the system to support all community members to share and co-construct their knowledge meaningfully and efficiently. The allocations of class time spent on independent note composition (i.e., SD-CK) versus community discussion (i.e., CDE) reflects the teachers' values for whole class discourse, and suggests that CK allowed for that discourse to happen.



*Figure 29.* Brad's and Jen's proportion of time spent on teacher-guided community discourse episodes involving the use of Common Knowledge (CDE), and time allocated for student-driven inquiry involving the use of Common Knowledge (SD-CK) throughout the 9-week WallCology inquiry unit. "No CK" activities did not involve the use of Common Knowledge.

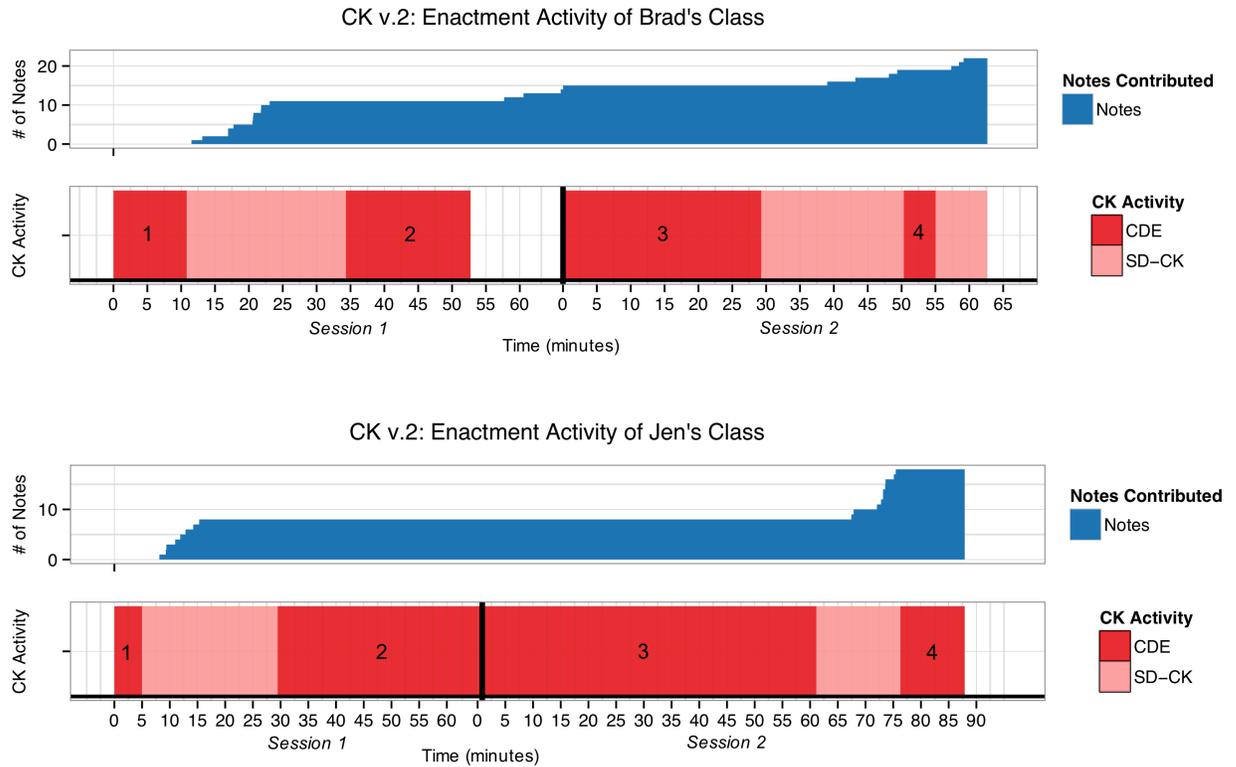
Two classroom sessions from each teacher were chosen for further analysis based on the richness of CK-driven discourse and opportunities for CK note contributions during the same session. We sought the class periods with the most uninterrupted usage of CK, in order to capture what might be construed as characteristic inquiry patterns, such as the "3R" orchestration cycle (Reflect-Release-Refocus) that was seen in the previous iteration with HelioRoom discussions. The two consecutive class sessions were chosen from the sixth and seventh weeks for Brad, and the seventh and eighth weeks for Jen. Figure 30 provides a composite timeline of both teachers' orchestrations of Common Knowledge activity during the two selected classroom sessions, showing alternating blocks of time between teacher-guided community discourse

episodes (CDE) and student-driven inquiry activities in the Common Knowledge environment (SD-CK). This recalls the “Catch-and-Release” activity pattern, where students are “caught” into community *reflection* discourse episodes, then “released” to work independently in the CK environment. The analysis of Iteration 1 enactments showed that the Catch phase consisted of two distinct elements: a reflective discussion where the teacher adopted several distinct orientations, and a refocusing instruction, to guide students’ subsequent inquiry work.



**Figure 30.** Activity timeline for both teachers’ orchestration of Common Knowledge activity during their two selected 90-minute class sessions. The dark vertical line delineates the end of the first session and the beginning of the teacher’s second class session. Community discourse episodes (CDE) were teacher-guided whole-class oral discussions that referenced students’ CK notes, typically on the IWB. During student-driven work periods (SD-CK), students shared their ideas, questions, and findings using CK notes. Blank periods on the timeline were occasions when the community engaged in inquiry activities during those two class sessions that did not involve Common Knowledge.

Figure 31 provides more details about the teachers’ orchestration of CK activity during the two class sessions. For each teacher’s enactment, a CK activity timeline appears on the bottom level, showing the activity sequences from Figure 30. The top “# of Notes” level above each activity sequence, juxtaposes the community’s note contribution activity, corresponding to SD-CK events in which the students work independently with CK. During the two class sessions, Brad’s students contributed 23 notes, while Jen’s students contributed 18 notes.



*Figure 31.* Enactment timeline for Brad's (top) and Jen's (bottom) orchestration of Common Knowledge activity during their two selected 90-minute class sessions. The dark vertical line delineates the end of the first class session and the beginning of his second session. For each teacher, the bottom (red) level shows the orchestration sequencing of teacher-guided community discourse episodes that referenced CK (CDEs) and student-directed work with CK (SD-CK). The top (blue) level shows students' note contribution activity. Over these two sessions, Brad's students contributed 23 notes, and Jen's students contributed 18 notes.

With respect to teachers' orchestration of WallCology inquiry phases, teachers followed students' engagement on one topic until they felt satisfied with how much progress students had achieved (i.e., as revealed by the WallCology dataset, CK notes, and whole class discussions), at which point they moved to the next phase. Towards the end of the WallCology unit, when the community had progressed through all of the phases, teachers allowed students to revisit any of the topics (i.e. using the various tabs in the WallCology application), to inform self-selected investigations.

## CK Version 2 Enactment: Discourse Patterns

Teachers were successful in using CK to help their students reflect about progress within the community, wonder aloud about patterns in their collective WallCology dataset, and share their data interpretations and theories. While not every CDE contained a clear 3R pattern, particularly the ones of longer duration (e.g., 30 minutes) where a variety of topics and discourse patterns occurred, there was an evident emphasis on reflective discussions that focused on the inquiry goals, progress evaluation, and a variety of reflective approaches. Almost all episodes (all 4 of Brad's, and 3 out of 4 of Jen's, as numbered in Figure 31) did end with refocusing instructions, which are summarized in Table 15, and includes the number of student-contributed CK notes reference by teachers during their CDE orchestrations. The one case in which Jen did not issue a refocusing instruction was CDE #2, which occurred at the end of the class period and hence did not warrant any further instruction, since students would not be resuming their inquiry activities.

Table 15  
*Teachers' Paraphrased Refocusing Instructions, Issued During Community Discourse Episodes*

Teacher CDE #	Number of Notes Referenced	Teachers' Refocusing Instructions
Brad CDE 1	0	Read Investigation Reports from last class. Add at least 1 CK note in which you formulate a theory or idea based on Investigation results, and tag your note.
Brad CDE 2	4	Teacher ends the session with CDE 2, but asks five students to capture the ideas they orally contributed during CDE 2, as a CK note.
Brad CDE 3	8	Choose 1 of the 4 "big topics" to work in, and you have a choice about how you want to work (e.g., write a CK note, run an investigation, do a population count, use any WallCology tool...)
Brad CDE 4	0	Since the "Investigation" tool isn't working properly today, compose a CK note to describe the investigation you would like to conduct.
Jen CDE 1	0	Contribute "ah-ha moments" in a CK note. "Ah-ha" learnings may stem from today's student-driven activity of reading other people's theories or from conducting a more refined investigation.
Jen	6	<None>

CDE 2		
Jen CDE 3	1	Of the following 5 trajectories, choose one topic to do further inquiry in: food web, investigation with environmental conditions, organisms, counts, habitat.
Jen CDE 4	4	We'll need to decide what to do next, now that there's a new species in the habitats. We know that there's competition, and that there are certain environmental conditions that will cause us to lose one of our species. We'll have to do more thinking about this to decide what we're going to do about this.

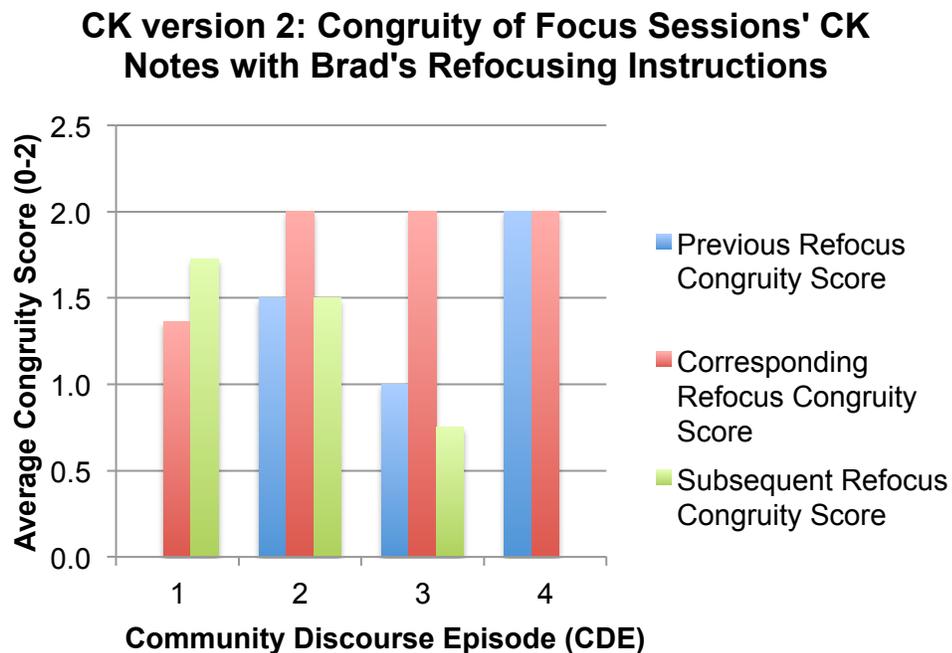
*Note.* CDE numbers correspond with CDE mappings on enactment timelines (Figure 31).

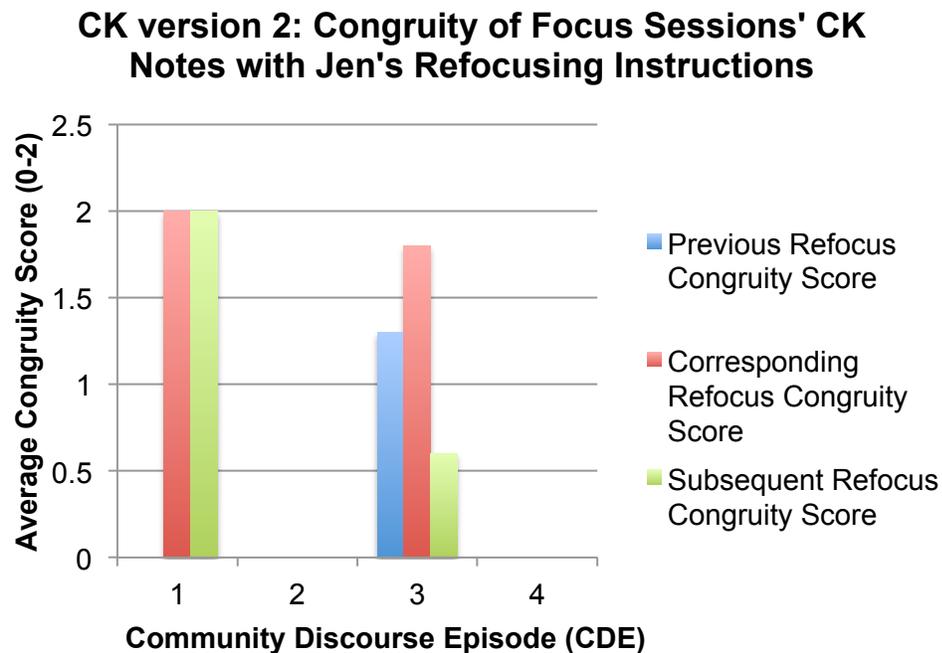
Brad's CDE 2 also occurred at the end of the CK-supported inquiry in the first class session, but he nevertheless issued refocusing instructions to four specific student work groups, and four notes were contributed after that (i.e., with students working after the class session had ended). This occurred because four student work groups made what Brad considered to be valuable oral knowledge contributions during this second CDE, and upon ending the inquiry session, Brad asked these four groups to capture what they had said, in CK notes. He subsequently uses these notes to spur discussion in his third CDE, with which he begins his next inquiry session.

Juxtaposing teachers' refocusing instructions with the enactment timelines demonstrates the presence of the Reflect Refocus Release orchestration cycle. From both teachers' enactment timelines (Figure 31) we see that students' note contributions occurred mainly during student-driven inquiry work periods in the CK environment (SD-CK).

To examine the effect of teachers' refocusing instructions on students' subsequent Common Knowledge note contributions, student-contributed CK notes were scored for congruity with refocusing instructions. Notes were scored for their "Corresponding Refocus Congruity" on

a 3-point scale (i.e., 2 = congruous; 1 = partially congruous; and 0 = not congruous) against the teacher's immediately preceding Refocus instructions from the corresponding CDE for a particular round of student note contributions. Each note was also scored for its "Previous Refocus Congruity" with the teacher's refocusing instruction issued in the previous CDE just prior to the round of student-directed CK activity (SD-CK) preceding the note's corresponding round of SD-CK. Figure 32 summarizes the average congruity scores for both classes. 20% of all notes contributed by both classes during teachers' selected focus sessions were independently scored for Corresponding Congruity with teacher's corresponding refocus instructions by this study's second rater and me. Inter-rater agreement was 88.9%, with Cohen's Kappa = 0.61. Inter-rater disagreements on Congruity scoring were related to the rater's limited understanding of the community's collective inquiry progress over the preceding sessions in the unit.





*Figure 32.* Average scores of CK notes for Brad’s and Jen’s focus sessions, indicating the note contribution round’s congruity with the refocusing instructions from: the previous CDE (Previous Refocus), the corresponding CDE (Corresponding Refocus), and the subsequent CDE (Subsequent Refocus). There were no Previous Refocus Instructions with which to score CK notes corresponding with CDE 1, hence there are no Previous Refocus scores for CDE 1. Jen’s CDEs 2 and 4 were culminating discussions and the final activity of each of the two sessions, hence no CK notes corresponding with CDEs 2 and 4 were contributed, nor were there any refocusing instructions issued. During the two class sessions, Brad’s students contributed 23 notes, while Jen’s students contributed 18 notes.

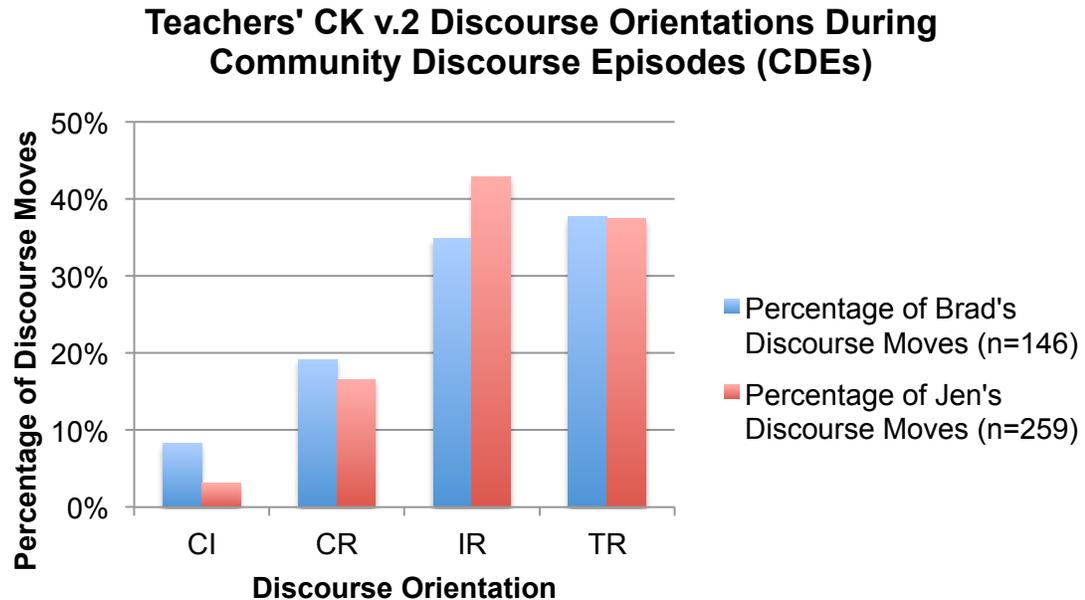
Figure 32 shows the average congruity scores for CK notes contributed during each teacher’s focus sessions, in relation to: (n) the current refocusing prompt issued during the current corresponding CDE (i.e., “corresponding refocus congruity”) – to which the batch of notes were presumably responding, (n-1) the refocusing prompt issued during the previous CDE (i.e., “previous refocus congruity”) – the one that notes were responding to prior to the current CDE’s refocusing prompt, and (n+1) the subsequent refocusing prompt issued in the subsequent CDE following note contribution (i.e., “subsequent refocus congruity”). The graphs confirm that student notes were more congruous with the immediately relevant (i.e. corresponding) refocusing

prompt, presumably because it contained instructions and orientations. For Brad's class, paired *t*-tests confirm that the mean Congruity Score of notes against their Corresponding (i.e., appropriate) Refocus Instruction is significantly higher than the mean Congruity Score of the same notes against the Previous Refocus Instruction, with  $t(11) = 3.37, p = 0.004$ . However, comparisons of congruity with Corresponding Refocus Instructions against their congruity with the Refocusing Instruction of the subsequent (i.e.,  $n + 1$ ) CDE are not significant, with  $t(18) = 0.72, p = 0.24$ . For Jen's class, similar tests showed that Corresponding Congruity Scores are significantly higher than the mean Previous Congruity Scores, with  $t(9) = 3.00, p = 0.008$ , as well as for Subsequent Congruity Scores with  $t(17) = 3.37, p = 0.002$ .

From the qualitative inspection of CDEs in the first iteration, four orientations of teacher-initiated exchanges were identified, which occurred primarily in the Reflection discussions: (1) Teacher Reflection (TR), in which the teacher engages in a personal reflection about recent ideas or progress; (2) Individual Student Reflection (IR), in which individual students or groups were posed an inquiry question; (3) Whole Class Reflection (CR), in which the teacher poses a reflection question to the classroom as a whole; and (4) Class Instruction (CI), in which the teacher issued straightforward instructions to the class. Our conjecture about teacher-guided discourse, in the design of CK iteration 2, was that the IR, TR, and CR orientations would be used by teachers to promote reflection on the community's collective knowledge base, and engage the community in discursive knowledge work.

Figure 33 shows a coding of all discourse orientations during teacher-guided community discourse episodes (CDEs), with each specific orientation graphed as a percentage of the total teacher discourse moves over the two focus sessions. This graph shows that both teachers prioritized teacher reflection (TR), with the observed purpose of modeling expert sense-making

and inquiry processes for the community. They also both emphasized individual student reflection (IR), oriented toward student reflection, engaging students in sense-making and inquiry processes.



*Figure 33.* Teachers' discourse orientations during community discourse episodes (CDE), as a percentage of teachers' total discourse moves, over their two respective focus sessions. Teachers' discourse orientations: giving instructional comments to the knowledge community (CI), inviting the knowledge community to reflect about a question or idea (CR), posing a question to an individual or student work group (IR), and teacher reflecting aloud (TR).

20% of teachers' video-recorded discourse moves during their selected focus sessions were independently coded for the four discourse orientations (CI, CR, IR, TR) by this study's second rater and me. Inter-rater agreement was 80.0%, with Cohen's Kappa = 0.72. Inter-rater disagreements were largely related to occasional difficulty in distinguishing between a teacher's Teacher Reflection (TR) and a Whole-class Instruction (CI) discourse move, stemming from the rater's limited understanding of the classroom community's inquiry context.

In an effort to examine how teachers use the community's collective knowledge in their inquiry discourse, I performed a grounded coding of the *functions* of teachers' discourse moves in each orientation. Nassaji and Wells (2000) developed a scheme of discourse analysis which integrates a sociocultural orientation with systemic functional linguistics and activity theory. Similarly to my own positioning of teachers' discourse as the mediator of technology-scaffolded collaborative inquiry, the authors recognize that "spoken discourse always occurs as a mediator of some purpose within a larger structure of joint activity" (p. 382), and note that "discourse can only be fully interpreted in relation to the purpose of the activity as a whole" (p. 383). Their work segmented major discourse episodes into various grain sizes, in order to capture different motivations or perspectives. Drawing upon their work, I segmented community discourse episodes (i.e., the CDE) into smaller topic sequence (TSeq), each of which consisted of a minimum of one exchange (Exch) between two speakers, starting with an Initiating move, followed by a Responding move, and then sometimes a Follow-up move by the initiator of the exchange. Table 16 defines the discourse segmentation units.

Table 16  
*Discourse Segmentation Units Used in Video Coding of Teacher-Guided Whole-Class Discourse*

<b>Code</b>	<b>Discourse Segmentation Units</b>
CDE	Community discourse episode involving the teacher and at least 1 student, and intended to include participation of the community.
TSeq	A topic of reflection discourse. May contain discursive teacher-student exchange(s).
Exch	A discursive exchange between a teacher and a student. Must contain an "Initiating" move and a "Responding" move, may also include a Follow-up move(s).

Figure 34 presents the further segmentation of CDEs in Brad's and Jen's discourse episodes into Topic Sequences. The average duration of a topic sequence orchestrated by Brad

during his two focus sessions was 3.6 minutes, and for Jen’s sessions was 3.8 minutes. The average duration of a teacher-student exchange orchestrated by Brad was 2.3 minutes, and for Jen’s sessions was 1.6 minutes. Although both teachers’ topic sequences were, on average, similar in length, Brad tended to orchestrate fewer but lengthier teacher-student exchanges. This implies that Brad’s teacher-student exchanges may have reached greater depth than Jen’s teacher-student exchanges.

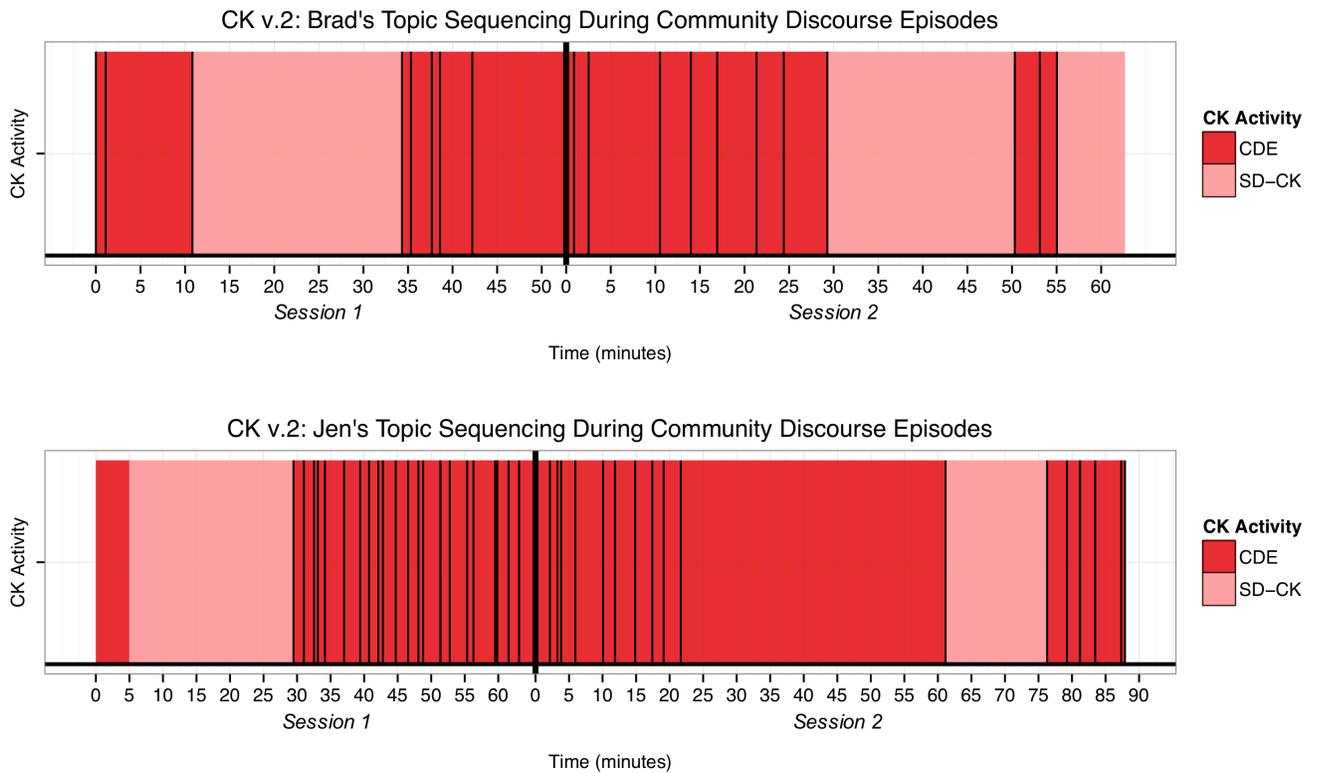


Figure 34. Brad’s and Jen’s activity orchestration timeline for two classroom sessions, of teacher-guided community discourse episodes (CDEs). Topic sequences (TSeq) nested within CDEs are bounded by thin black vertical lines.

Table 17 summarizes the frequency and duration of sequences and exchanges for all community discourse episodes in the two teachers’ selected class sessions. Overall, Jen spent approximately 56% more time in community discourse during those two sessions (113.8 minutes for Jen, versus 63.3 minutes for Brad), but had more than twice as many topic sequences (a total

of 39 sequences for Jen versus 17 in total for Brad) and approximately 36% more exchanges (a total of 66 exchanges for Jen versus 24 in total for Brad). Thus, Jen had a greater level of interactivity (exchanges and sequences) than Brad, with a shorter average duration for topic sequences and exchanges.

Table 17  
*Frequency and Duration of Discourse Segmentation Units Occurring in Teachers' Focus Sessions*

	Brad Session 1		Brad Session 2		Jen Session 1		Jen Session 2	
	CDE 1	CDE 2	CDE 3	CDE 4	CDE 1	CDE 2	CDE 3	CDE 4
<b>Duration</b> (minutes)	10.8	18.4	29.3	4.7	5.0	36.1	61.1	11.6
<b># of Topic Sequences</b>	2	5	8	2	1	23	10	5
<b># of Teacher-Student Exchanges</b>	4	6	14	0	0	41	21	4
<b>Average Topic Sequence Duration</b> (minutes)	5.4	3.7	3.7	1.8	5.0	1.6	6.2	2.3
<b>Average Exchange Duration</b> (minutes)	2.4	3.0	1.4	N/A	N/A	0.9	1.2	2.8

After segmenting all four sessions' (2 sessions per teacher) video into topic sequences and exchanges, the grounded coding of teachers' discourse moves was performed, with the goal of illuminating the ways in which teachers used the community knowledge (e.g., Wallcology displays or Common Knowledge IWB displays). Tables 18-21 present the coded discourse functions for each orientation, as well as their frequency of occurrence, followed by short discussions of how these functions were employed within each orientation. The amount of time a teacher spent on each discourse code is also presented as a percentage of the teacher's total

time spent on community discourse episodes, noting that there were many instances of code co-occurrence. The occurrence frequency of a discourse code would give some indication of the code's prominence as a discursive orientation and function of knowledge work.

Table 18  
*Inquiry Scaffolds with a Class Instruction (CI) Orientation*

<b>Inquiry Discourse Scaffold</b>	<b>Description</b>	<b>Percentage of Brad's Discourse Moves</b>	<b>Percentage of Jen's Discourse Moves</b>
CI-Grp	<i>Grouping</i> : teacher defines with whom students will work, either generally (e.g., "Work with a partner") or specifically (e.g., "Natalie and Jarrett can work together").	1.4%	--
CI-Rec	<i>Recall</i> : teacher recollects what the community did in a prior class, to activate students' prior knowledge/experiences.	2.1%	1.2%
<b>CI-Refo</b>	<b><i>Refocus</i></b> : teacher gives instructions to community about what to contribute to Common Knowledge and/or what inquiry tasks to do, in subsequent student-directed inquiry activity.	2.7%	0.8%
CI-SMC	<i>Subject-matter Content</i> : teacher delivers subject-matter content knowledge to the community.	--	0.4%
CI-TI	<i>Technology Instruction</i> : teacher demonstrates to the community how to use a particular technology.	2.1%	0.8%

*Note.* CI-Refo represents the "Refocus" phase of the 3R orchestration cycle in preparation for the subsequent "Release" phase of the 3R cycle, in which students are released to pursue student-driven inquiry activities.

Inquiry discourse scaffolds with a Class Instruction (CI) orientation are generally logistical or directive in nature. The CI-Rec (Recall) function was typically observed at the start of a community discussion, as a way to summarize what the community had accomplished previously or refresh students' memory about a previous issue, with the intent to motivate forward progress (i.e., from where the community had last left off). The CI-TI (Technology Instruction) function addressed how to use various tools in the WallCology application, or explained various CK functions. The CI-Refo (Refocus) function captures the "Refocus" phase

of the 3R orchestration cycle, and refers specifically to teachers' instructions for the upcoming "Release" phase, to guide students' inquiry activities. As in iteration 1, the WallCology enactment demonstrated again that teachers issued refocusing instructions in community discourse episodes preceding student-driven inquiry work periods in the Common Knowledge environment. Occurrences of the CI-Grp (grouping) function often followed CI-Refo, just before the students were "Released" to establish their working groups.

Table 19  
*Inquiry Scaffolds with a Community Reflection (CR) Orientation*

<b>Inquiry Discourse Scaffold</b>	<b>Description</b>	<b>Percentage of Brad's Discourse Moves</b>	<b>Percentage of Jen's Discourse Moves</b>
CR-Big	<i>Big Ideas:</i> teacher asks community to articulate a big idea(s) or common theme(s); or categorize knowledge artifacts (e.g., Common Knowledge notes) into big ideas or themes.	--	2.7%
CR-Build	<i>Build-on:</i> teacher solicits connections, build-ons, justifications, or counter-arguments from the community. (Inspired by Nassaji & Wells, 2000)	6.2%	--
CR-Epi	<i>Epistemic Goals:</i> teacher asks the community to comment upon the community's current epistemic goals, approaches, and strategies, or suggest new ones.	1.4%	4.6%
CR-Ex	<i>Explain:</i> teacher asks the community to validate, clarify, explain, and/or elaborate on what they just said, or what has been written in a community knowledge artifact(s) (e.g., Common Knowledge note).	1.4%	1.5%
CR-Gap	<i>Gaps:</i> teacher asks the community to comment on discrepant/inconsistent information (i.e. in students' observational data), or identify knowledge gaps in the community's collective knowledge base.	--	0.4%
CR-Q	<i>Question:</i> teacher asks the community to answer a hypothetical or rhetorical question related to the inquiry task at hand.	4.8%	2.7%
CR-Rec	<i>Recall:</i> teacher asks the community to recollect what they did in a prior class, to activate students' prior knowledge/experiences.	0.7%	0.4%
CR-Rel	<i>Relate:</i> teacher asks the community to relate their current inquiry to prior knowledge/experiences, real-world examples, primary data (e.g., student observations), and/or the phenomena being observed/investigated.	2.1%	1.2%

CR-Role	<i>Role Casting:</i> teacher positions/animates the community in an inquiry or disciplinary role (e.g., thinker, hypothesizer, position holder, idea originator, scientist, etc.). (Inspired by O'Connor & Michaels, 1996; Yamakawa, Forman, & Ansell, 2005)	2.7%	1.9%
CR-Syn	<i>Synthesize:</i> teacher asks the community to synthesize conceptual connections between multiple knowledge artifacts (e.g., Common Knowledge notes).	--	1.2%

Inquiry discourse functions with a Community Reflection (CR) orientation were used by teachers to engage the community in inquiry reflection. These typically occur in the form of reflective questions directed at the community – not at a particular student or student work group. The CR-Rec (recall) function often occurred at the start of a community discussion, as a way to ask the class to reflect on what the community had most recently accomplished, with the intent to motivate progress in the collective inquiry. The CR-Role (animate in role) function often co-occurred with CR-Ex (explain or elaborate) function – as when, for example, a teacher asks the community for elaboration of common observations or ideas that appeared across multiple CK notes, while simultaneously casting students into the role of observer, inquirer, or theorizer. Such fluid role positioning manifests social and psychological conceptualizations of a student's self-identity formation as well as his/her identity among peers (Yamakawa et al., 2005). In addition to CR-Ex, two other CR-oriented inquiry functions explicitly engaged the community in reflecting upon the collective knowledge base of CK notes: CR-Gap (address gaps or inconsistencies in CK notes or observational data), and CR-Syn (request students to synthesize across several CK notes). Other CR discourse functions engaged the community in extending the ideas captured in CK notes, such as: CR-Build (build-on ideas), CR-Rel (relate to other ideas or experiences). In general, the teacher employed CR functions to move the reflection discussion

forward, widely solicit ideas that could be used (i.e., by the teacher) to advance a discourse thread or narrative, and allow the community to add new insights, organizational schemes, or inquiry directions.

Table 20  
*Inquiry Scaffolds with an Individual Reflection (IR) Orientation*

Inquiry Discourse Scaffold	Description	Percentage of Brad's Discourse Moves	Percentage of Jen's Discourse Moves
IR-Big	<i>Big Ideas:</i> teacher asks an individual student (or student workgroup) to articulate a big idea(s) or common theme(s); or categorize knowledge artifacts (e.g., Common Knowledge notes) into big ideas or themes.	--	5.8%
IR-Build	<i>Build-On:</i> teacher solicits connections, build-ons, justifications, or counter-arguments from individual student or working group (e.g., a student pair)	6.2%	--
IR-Epi	<i>Epistemic Goals:</i> teacher asks an individual student (or student work group) to comment upon the community's current epistemic goals, approaches, and strategies, or suggest new ones.	--	4.6%
IR-Ex	<i>Explain:</i> teacher engages an individual student (or student work group) to explain, clarify, and/or elaborate on their contributed knowledge artifact (e.g., Common Knowledge note).	10.3%	8.9%
IR-Gap	<i>Gaps:</i> teacher asks an individual student (or student work group) to comment on discrepant/inconsistent information (i.e. in students' observational data), or articulate knowledge gaps in the community's collective knowledge base.	--	0.4%
IR-Q	<i>Question:</i> teacher asks an individual student (or student work group) to answer a hypothetical or rhetorical question related to the inquiry task at hand.	4.8%	5.0%
IR-Rel	<i>Relate:</i> teacher asks an individual student (or student work group) to relate their contributed knowledge artifact (e.g., their Common Knowledge note) to prior knowledge, real-world examples, primary data, and/or the phenomena being observed/investigated.	--	1.5%
IR-Role	<i>Role Casting:</i> teacher positions/animates an individual student (or student work group) in an inquiry or disciplinary role (e.g., thinker, hypothesizer, position holder, idea originator, scientist, etc.). (Inspired by O'Connor & Michaels, 1996; Yamakawa, Forman, & Ansell, 2005)	19.9%	14.3%
IR-Syn	<i>Synthesize:</i> teacher asks an individual student (or	--	2.3%

	student work group) to synthesize conceptual connections between their contributed knowledge artifact (e.g., their Common Knowledge note) and at least one artifact in the community's collective knowledge.		
--	--	--	--

The Individual Reflection (IR) orientation was employed by teachers to engage individual students or student groups in strategically chosen inquiry reflections. IR-oriented discourse functions often followed a teacher's CR-oriented scaffold – e.g., the teacher asked the community something, then chose a student to respond to the same or similar question. The IR-Role (casting students in a specific inquiry role) often co-occurred with IR-Ex (eliciting explanations) - as when, for example, a teacher asked a student for further explanation of their CK note, simultaneously casting the student in the role of observer, inquirer, or theorizer – and publicly positioning the student as a legitimate “expert” participant (Yamakawa et al., 2005; O'Connor & Michaels, 1993; Lave & Wenger, 1991b), contributing to the student's identity formation as a learner. Other IR-oriented discourse functions that explicitly engage the individual in reflecting upon individual or collective CK contributions (mirroring the CR orientation above) include: IR-Gap, and IR-Syn. IR-oriented discourse functions that engaged individuals in extending the ideas from CK notes, included: IR-Build, IR-Rel, IR-Big, and IR-Epi.

In general, teachers used the IR orientation to help create exemplary statements in the discussion that could be brought to bear on a particular line of reasoning, or otherwise to advance a discourse narrative. Some IR functions, like IR-Big and IR-Epi, typically occurred near the end of the CDE reflection phase, as a means of inquiry discourse scaffolds used to influence their subsequent Refocus instructions (i.e., CI-Refo). Many of the other IR functions were used

to evoke students' responses that could serve to establish the presence of a certain perspective within the class community, or raise a particular line of inquiry. The teacher might then revoice what the students had said, in order to help norm that point of view, or create a tension that could motivate further inquiry. Such comments would come in the TR (Teacher Reflection) orientation, discussed next.

Table 21  
*Inquiry Scaffolds with a Teacher Reflection (TR) Orientation*

<b>Inquiry Discourse Scaffold</b>	<b>Description</b>	<b>Percentage of Brad's Discourse Moves</b>	<b>Percentage of Jen's Discourse Moves</b>
TR-Big	<i>Big Ideas</i> : teacher reflects aloud, articulating a big idea(s) or common theme(s); or categorizing knowledge artifacts (e.g., Common Knowledge notes) into big ideas or themes. Creates alignments in the community discourse.	3.4%	5.4%
TR-Epi	<i>Epistemic Goals</i> : teacher comments upon the community's current epistemic goals, approaches, and strategies, or suggests new ones.	4.1%	4.2%
TR-Ex	<i>Explain</i> : teacher reflects aloud to validate or seek confirmation in clarifying, explaining, and/or elaborating on what a student(s) just said, or what a student(s) has written in a community knowledge artifact(s) (e.g., Common Knowledge note).	21.2%	13.5%
TR-Gap	<i>Gaps</i> : teacher reflects aloud, comments on discrepant/inconsistent information (i.e. in students' observational data), or identifies knowledge gaps in the community's collective knowledge base.	--	1.9%
TR-KCon	<i>Knowledge Convergence</i> : teacher confirms socially-negotiated knowledge convergence (e.g., by writing the big idea in a semi-permanent publicly visible space). A "rise above".	0.7%	4.6%
TR-ReBr	<i>Rebroadcast</i> : teacher laminates/fuses their phrasing/information onto the student's contribution, and rebroadcasts a student's (or student workgroup's) reasoning to the community (e.g., "What Terry just said..."). (Inspired by O'Connor & Michaels, 1996)	2.1%	5.8%
TR-Rel	<i>Relate</i> : teacher reflects aloud, relating student note(s) and/or spoken contribution(s) to the community's: prior knowledge/experiences, real-world examples, primary data, and/or the phenomena being observed/investigated.	1.4%	0.4%
TR-Syn	<i>Synthesis</i> : teacher reflects aloud, synthesizing conceptual connections between multiple students'	4.8%	1.5%

	notes and/or spoken contributions.		
--	------------------------------------	--	--

The Teacher Reflection (TR) orientation was employed by teachers to make their own ideas or interpretations explicit to the community. The teacher positions him or herself as a co-investigator within the community and models various forms of reflection, interpretation or argumentation, in reference to students' ideas as represented in CK notes. Often, the teacher would adopt this orientation in response to a previous exchange where a different orientation had been the focus. For example, the TR-Ex often followed IR-Ex or CR-Ex – as when a teacher asked the community or a student for further explanation of a CK note, then paraphrased (i.e., revoiced) the student's response to confirm with the student whether s/he had understood him/her correctly. This approach empowered the student to evaluate what the teacher had just said, and even to correct the teacher if necessary – a somewhat inverted pattern from the traditional I-R-E pattern, where the teacher initiates, student responds, and teacher evaluates (and power rests with the teacher as the evaluator).

With the exception of TR-Epi (epistemic progress) and TR-KCon (knowledge convergence) functions, the TR orientation generally played the role of helping teachers to re-voice students' written and spoken contributions to the collective inquiry, thus serving to align students with one another and with the teacher, as “proponents of a particular hypothesis or position relative to the problem at hand,” and helping students to “take on target intellectual roles” (O'Connor & Michaels, 1996; p. 66). In this way, teachers use language to socialize students into intellectual practices during community discussions, and to motivate new directions or priorities for their collective inquiry. A teacher's revoicing of student ideas may serve to: (1) credit a student for their contribution while clarifying it, (2) animate/cast a student into an intellectual/inquiry role thereby socializing him/her as legitimate participants of intellectual practices, (3) laminate/fuse phrasing/information onto a student's contribution as they

rebroadcast the student's ideas while casting the student as a speaker in a larger public sphere, and (4) connect students' ideas to each other (O'Connor & Michaels, 1996c).

There are several TR-oriented functions whereby teachers explicitly model some form of reflection in reference to students' individual or collective CK notes, including: TR-Ex, TR-Rel, TR-Gap, and TR-Syn. Other TR-oriented functions served to extend or progress upon the ideas captured in CK notes, such as: TR-Big (Big ideas), TR-Epi (Epistemic Goals), and TR-KCon (Knowledge Convergence). The TR-KCon function was typically employed as a means of solidifying the community's social acceptance of certain themes or directions, as when the teacher guides the community into connecting two (or more) big ideas to arrive at a knowledge convergence that was socially negotiated and now legitimized as a community artifact of knowledge convergence by being recorded in a semi-permanent persistently displayed wall chart in the classroom. Again, the outcomes of these TR functions typically guided subsequent discourse moves, in all of the orientations, to result in an orchestration of the reflective phase of the 3R cycle.

Tables 18-21 illustrate the complex nature of orchestrating productive inquiry discourse, involving factors of topic sequencing, interlocutor interaction (e.g., teacher-student exchanges, discourse orientations), and orchestrating the "knowledge work" of students within and between various phases of the inquiry unit. In all discourse episodes, teachers referred to students' CK notes as a mean of informing the discourse. The codes discerned through the open coding of teacher-guided discourse support the notion of an orchestration cycle in which teachers "catch" students and enter into *reflective* discussion, using a variety of orientations that feed into one another, empowering students through revoicing and role casting, to ultimately motivate a *refocusing* of the community's attention and then the *release* of students back into more

independent inquiry. During the Reflection phase of the 4R cycle, teachers leverage CK notes and other community knowledge artifacts as a resource for their various queries to students. Knowledge gaps or big ideas that emerge from such discourse subsequently shape teachers' refocusing instructions, which in turn influences the trajectories of subsequent collective knowledge work in the CK environment.

### **CK Version 2 Implications: Design Goals for CK Version 3**

The WallCology iteration of CK was much more substantive than the HelioRoom iteration, with deeper conceptual content, more sophisticated simulations and forms of evidence, and reflections about patterns of data and methodological approaches. CK served to scaffold the progression of inquiry through six distinct phases, playing an orchestrational role by helping teachers achieve their desired “script”, sequence, or progression of inquiry activities. The technology was well-suited for inquiry, accommodating a wide range of student inputs and teacher-guided engagements, and well-matched to the epistemic commitments of KCI, supporting students in developing a shared knowledge base and then supporting teachers as they guided students to using that knowledge base as a resource. However, the technology environment itself was somewhat agnostic to the particular WallCology phase in which it was being used, varying only slightly in terms of the available tags. Teachers were left to their own (very capable) devices to find creative and constructive ways of advancing the discourse and inquiry focus. Table 22 presents the limitations of iteration 2 technology and activity sequences, mapped to some redesign goals for iteration 3.

Table 22

*Limitations of Iteration 2, and Corresponding Redesign Goals for Iteration 3*

	<b>Iteration 2 Limitations</b>	<b>Technology Redesign Goals for Iteration 3</b>
<b>Individual</b>	No build-on "write" capabilities.	Enable build-on authoring capabilities.

<b>Tablet Interface</b>		
	Tags were not user-generated or socially-negotiated, and did not fit the community's conceptual categorization of their ideas/questions.	Enable user-generated tags.
	Relied on curriculum design and teacher scaffolding, to promote reading of peers' notes, to make peer-to-peer conceptual connections.	Provide technological support for access and conceptual connections to peers' notes.
	Provided a sense of inquiry productivity (i.e. quantity of note contributions), but relied on WallCology application and curriculum design to provide sense of inquiry progress.	Provide a sense of inquiry progress.
<b>Public IWB Interface</b>	Heavy orchestration load on teachers to monitor incoming notes and manage classroom concurrently, though note filters mildly lessened this load when used to organize and de-clutter workspace.	Organize incoming notes/ideas. Increase the level of semantic visualization to organize community's incoming ideas.
	Relied on teachers' classroom management skills, curriculum design, and teacher scaffolding; to get and maintain student attention, and to manage student groupings for different activities.	Support classroom management tasks such as: helping the teacher get and maintain student attention, manage flexible student groupings for different activities.
	Did not visualize community's idea connections or idea growth.	Visualize community's idea connections or idea growth.
	Provided a sense of inquiry productivity (i.e. quantity of note contributions), but relied on WallCology application and curriculum design to provide sense of inquiry progress.	Provide a sense of inquiry progress.
	Not enough scaffolding for community knowledge convergence. Heavy reliance on teacher scaffolding to promote knowledge convergence.	Provide students with more technology scaffolds to work towards knowledge convergence.

In the next iteration, the CK environment will play a more central role in managing the products and progress of student inquiry. New technology features will support the movement

from one inquiry phase to the next, including the use of intelligent agents that distribute CK notes to students for tagging and interpretation. There are also increased structural aspects for the curriculum overall, with CK taking dramatically different forms across three major inquiry phases. As discussed in Chapter 3, the curricular context for the next iteration was astronomy, with the overall design approach of supporting small groups to work independently on a set of community-driven inquiry themes. In the next iteration, the CK technology look and function will be carefully matched to the specific inquiry goals and activities for different phases of the script. In this way, the third iteration of CK can address an important issue of how much structure can be given to orchestrational systems, and what forms of discourse and inquiry may be enabled or compromised.

## Chapter 5: Iteration 3 Findings

### **Common Knowledge Version 3: Astronomy Inquiry**

The third iteration of CK introduced new features to enable students to work on their peers' notes and to support teachers in progressing between inquiry phases. For example, the automatic processing of students' notes was introduced, to enable their redistribution to peers for follow-up "knowledge work." We also supported distinct inquiry phases within CK, such that the system as a whole progressed from one phase to the next, each with distinct functions and representations. Prior iterations of CK had been integrated within a broader scaffolding environment where CK was designed to support student reflections and knowledge building within the distinct phases of the curriculum script, providing the teacher with an accessible representation of student ideas that could support whole class discussions and ultimately motivate the progression between inquiry phases. In iteration 2, for example, the CK tool was employed amongst eight other software applications that helped students add observations about the WallCology simulation (i.e., the habitats, organisms, life cycles, and food web relationships). In the present iteration, CK was not embedded within any broader technology suite, but rather, served as the primary environment within a 10-week astronomy unit, guiding progression between three distinct inquiry phases: *Brainstorm*, *Propose*, and *Investigate*.

### **CK Version 3: Responding to Design Recommendations from CK Version 2**

As in previous versions of CK, this iteration enabled students to contribute ideas as well as to access their peers' contributions from a collective knowledge base. The curricular goal was to guide students' astronomy inquiry, targeting the required content expectations (gravity, scale, and nested systems), and supporting students' independent inquiry investigations. In the first

distinct phase, called *Brainstorm*, distinct technology scaffolds were created to help students create and tag their initial interests. In the next phase, called *Proposal*, CK supported students as they built proposals to address their initial brainstorm ideas and collectively identify the most promising proposals (Chen et al., 2012). In the third phase, called *Investigate*, students addressed the proposals through investigations of their own design. In addition to the use of intelligent agents to process student contributions, this iteration also introduced an emphasis on the physical classroom as a means of spatially distributing knowledge representations and guiding student inquiry. This was achieved within the *Investigate* phase by distributing distinct student-identified inquiry topics (e.g., “stars and nebulas”, “moons, gravity, and orbits”) into distinct regions of the classroom. Once again, CK included a tablet user interface for independent student knowledge work and an IWB interface to support teacher-guided community discussions, as well as occasional student interactions. Teachers indicated in post-run interviews that having different interfaces on the tablet (for individual student use) and on the IWB (for classroom community use) was a good way to ensure that students “look up” at the Common Board on the IWB to gain a community-wide awareness of idea relations in the collective knowledge base. Table 23 summarizes how iteration 3 responded to the redesign goals articulated in the previous chapter.

Table 23  
*Iteration 3 Technology Features that Respond to Redesign Goals*

	<b>Technology Redesign Goals for v. 3</b>	<b>CK v.3 Response to Redesign Goals</b>
<b>Individual Tablet Interface</b>	Enable build-on "write" capabilities.	"New Notes" composed during Phase 1 (Brainstorm) were, by default, root notes of possible future note threads. "Build-on" notes appeared sequentially concatenated to the root note.
	Enable user-generated tags.	Technology script defined a one-time event, when the teacher generated 4 socially-negotiated tags during Phase 1 (Brainstorm), that persisted through the rest of the inquiry phases and shaped community inquiry trajectories.

	Provide technological reason/incentive to read peers' notes and make conceptual connections to them.	The "Inquiry" voting tool in Phase 2 (Propose) allowed learners to indicate which inquiry proposals held potential, and the "Knowledge Connection" voting tool in Phase 3 (Investigate) allowed learners to indicate which peers' notes had conceptual connections to their own notes.
	Provide a sense of inquiry progress.	A unidirectional forward-progressing technology script scaffolded the community through 3 phases of inquiry: Brainstorm, Propose, and Investigate. Phases determined what notes were accessible from tablets.
<b>Public IWB Interface(s)</b>	Organize incoming notes/ideas. Perhaps use a semantic visualization to organize community's incoming ideas.	4 socially-negotiated tags were created in Phase 1 (Brainstorm), visually organized notes in a tag-based tree and also filter notes
	Support classroom management tasks such as: helping the teacher get and maintain student attention, manage flexible student groupings for different activities.	"Pause" button suspended all students' CK activity on tablets. "Resume" button allowed CK students' activity to resume on tablets.  Each tag (and associated notes) became an inquiry "interest group" with its own public display, in Phase 3 (Investigate). Students could fluidly enter/exit any interest group as they wished.
	Visualize community's idea connections or idea growth.	5 public displays: "Common Board", 4 "Topic Boards" (Phase 3 only); organized notes in a tag-based tree. Common Board displayed all tags and corresponding notes. Topic Boards displayed 1 tag's Inquiry Proposals and corresponding reports, organized in a proposal-based tree.
	Provide a sense of inquiry progress.	A forward-progressing technology script scaffolded the community through Brainstorm, Propose, and Investigate phases. Public displays were distinctly different for each phase; and included a button, enabling teachers to initiate the next inquiry phase, and hence, a change in "technology state" for both the public (IWB) and individual (tablet) interfaces.
	Provide students with more technology scaffolds to work towards knowledge convergence.	Word cloud available on public display(s) in Phases 1 (Brainstorm) and 3 (Investigate), which visualized popular words/ideas contained in notes.  Results of "Promising Inquiry" and "Knowledge Connection" voting tools aggregated on corresponding note icons in Phases 2 (Propose) and 3 (Investigate) respectively.  Results of word clouds and voting tools sparked discussions towards knowledge convergence.

### CK Version 3: Design Analysis

Common Knowledge played a central role in supporting the 10-week KCI script for grade 5/6 astronomy, targeting the main topics of gravity, scale, and nested systems (Ontario Ministry of Education, 2007). Since this unit had no Embedded Phenomena to serve as a persistent object for student inquiry, teachers felt that they could use CK within a knowledge building approach to help students define, share, and address the inquiry topics they found most interesting (Zhang et al., 2009). The two teachers were experienced in knowledge building, and a primary design goal was for CK to help teachers guide the students in inquiry and knowledge building such that the community made progress on those topics. However, all members of the research team were aware that CK might introduce a level of scripting or directedness that would diverge somewhat from the Knowledge Building principles (i.e., Scardamalia, 2002).

Throughout the multi-week enactment, the teachers' role was to help move the community through the various phases of the inquiry script, with transitions between phases supported by the CK technology. As they had in previous iterations, it was expected that teachers would use CK during class sessions as a tool for launching oral classroom discussions and accessing student ideas (i.e., for purposes of revoicing, synthesizing, etc.).

For the first seven weeks (90-minute class periods, twice per week) the CK technology script was closely coupled to an inquiry script consisting of the three progressive phases mentioned above: *Brainstorm*, *Propose*, and *Investigate*. For the final three weeks, students worked on a culminating inquiry project, which did not entail any creation of CK notes. Hence, the analysis of CK in this iteration will focus on the first 7 weeks of the inquiry script. Phase one was the *Brainstorm* phase, lasting three weeks, in which students shared ideas, questions, and evidence-based hypotheses based on various classroom “hook” activities (Dunkhase, 2003) designed to stimulate interest in astronomy topics. In week four – the *Propose* phase – CK

supported students in defining possible inquiry trajectories (called proposals) based on their Brainstorm notes. This was followed by the *Investigate* phase in weeks 5-7, in which students worked in small “interest groups” (n = 1, 2 or 3) to address their proposals by conducting experiments, reading reference materials, and reporting their findings.

The technology script was designed to supported collaboration across individual, small group, and community “social planes” (Stahl, 2013) within the classroom, enabling students to work as individuals or as small groups in the first two phases, and to join a topic-based interest group (and move between groups at any time) during the *Investigate* phase. For each of the three phases, the CK technology environment was cast in a specific form, with features and functions designed to support the activities and interactions particular to that phase. The CK tablet supported students as they contributed, built-on, and tagged notes, sometimes automatically sending them a subset of peers’ notes that matched their selected preference. For each of the three inquiry phases, CK offered students distinct note “types” that included defined input fields preceded by specific instructions or “prompt”. Table 24 summarizes the note types employed in each inquiry phase, and indicates whether build-on notes were possible.

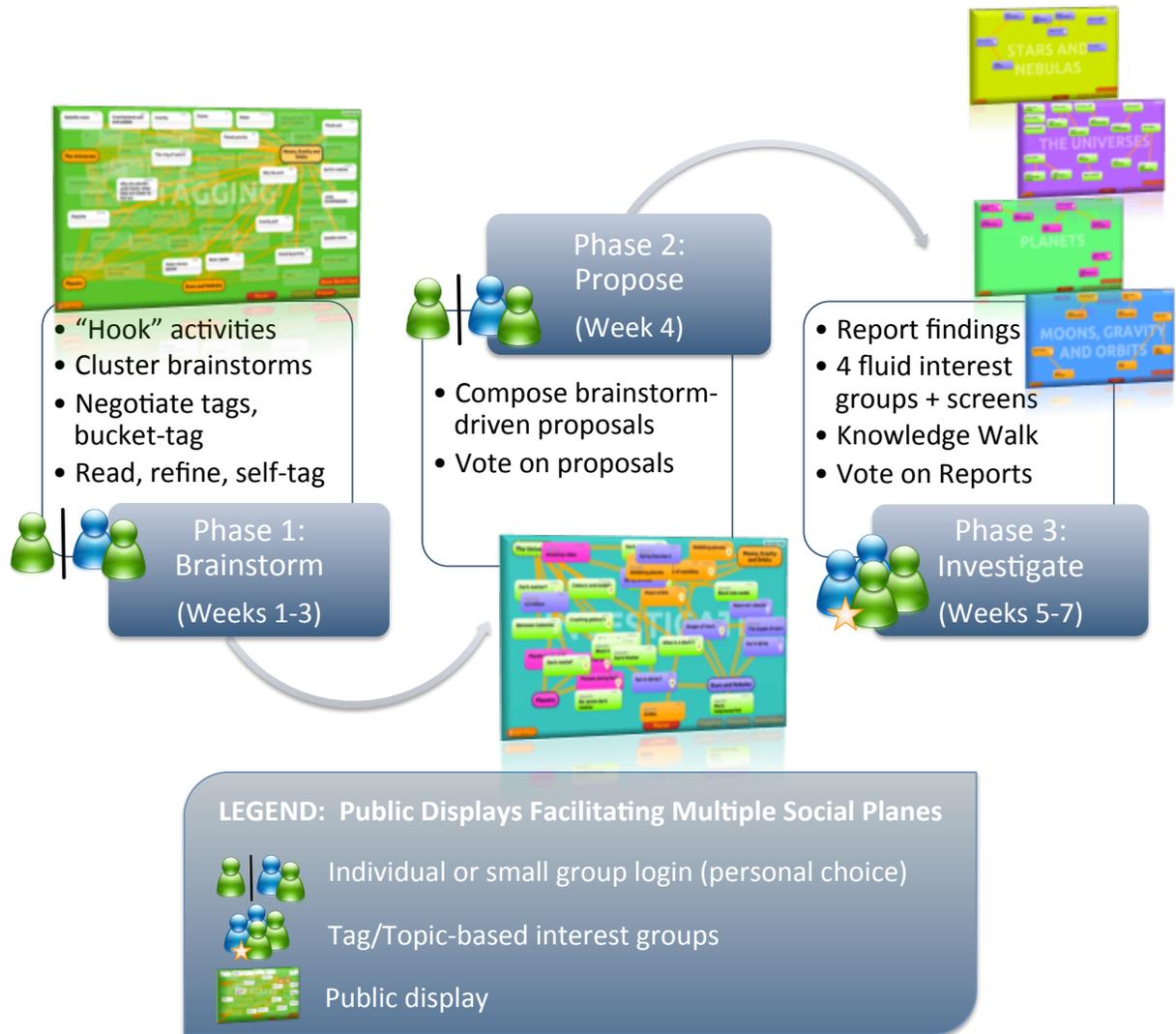
Table 24  
A Summary of CK Note Scaffolds for Each Inquiry Phase

	<i>Phase 1 Brainstorm</i>	<i>Phase 2 Propose</i>	<i>Phase 3 Investigate</i>	
	<b>Brainstorm Note</b>	<b>Proposal Note</b>	<b>Inquiry Report</b>	<b>Experiment Report</b>
<b>Text Field 1</b>	NEW NOTE	PROPOSAL What should we do? How should we do it?	NEW INFORMATION What new information have you observed, measured, or read about?	QUESTION What question are you investigating?
<b>Text Field 2</b>	--	JUSTIFICATION What might we	REFERENCES What resource(s) did	HYPOTHESIS Make an educated

		learn?	you use to learn this? (e.g. simulation name+URL, book title+author, information website name+URL, etc.)	guess about how this works!
<b>Text Field 3</b>	--	--	--	<b>METHOD</b> How will you test your hypothesis?
<b>Text Field 4</b>	--	--	--	<b>RESULTS</b> Share all your observation and/or measurements from your experiment.
<b>Text Field 5</b>	--	--	--	<b>CONCLUSIONS</b> Analyze your observations and/or measurements to see if your hypothesis is true or false!
<b>Build-ons?</b>	✓	✗	✗	✗

The CK “Common Board” IWB public display was also designed with specific features and affordances to serve as an “orchestration tool” (Dillenbourg et al., 2012). Such features included a “Pause” button – allowing teachers to instantaneously capture student attention by blocking all tablet access to CK, and a “Resume” button to instantaneously allow students to resume their CK activity. The Common Board also included special-purpose buttons that teachers used to move from one phase of inquiry to the next – effectively changing the technology state universally on all CK devices, and advancing the community to a new aspect of the inquiry script. Another new feature was the addition of four “Topic Boards” in the *Investigate* phase – public displays to support special interest groups. In addition to representing

the community's progress in each phase (i.e., Brainstorm, Propose, Investigate), the CK Common Board also represented the community's notes, tags, and votes. Figure 35 summarizes the phases of inquiry, public display formats, and collaboration groupings of the technology and inquiry script.



*Figure 35.* The 7-week CK-supported inquiry and technology script, with different public displays configured for the three phases, and students supported in various social planes.

### ***Phase 1: Brainstorm***

The *Brainstorm* phase began by engaging students in the exploration of digital simulations, the creation of models using tangible materials, and the exploration of reference materials in print and digital media. In addition, the HelioRoom EP (Thompson & Moher, 2006) was employed as an introductory “hook” activity, requiring a single 90-minute class period for students to uncover the planetary identities of all the coloured circles. These introductory activities triggered ideas and questions, which were recorded by students on their tablets as CK Brainstorm notes. These notes appeared on the classroom’s IWB Common Board display as moveable white note icons that could be clustered by teachers, and could also be read and built upon from students’ tablets (Figure 36). In addition, a word cloud representation was accessible from the Common Board, providing a potentially engaging visualization of the dynamically emerging content within the brainstorm (Figure 37).





The image shows a Common Board (IWB) display with the following elements:

- Notes and Clusters:**
  - Galaxies:** Galaxy (allie), Galaxy colour (josh), Galaxies (jamie)
  - Gravity:** Gravity pull (nora), Gravity (robert), Gravitational pull and wobble (jamie), Planet gravity (kay), Rock ripples (erica)
  - Nebulas:** Purple (kay), Nebulas (sarah), What's a nebula (rafe)
  - Moons:** Moons (kay), Speedie moons (nora), Speedie moon (nora), Mooning aravitv (noah), Moon versus planet (noah), Saturn's asteroids (erica)
  - Stars:** Stars and different colors! (rayn), Stars (charlotte), Star clusters (alastair), Stars (noah), Sun energy (charlotte), Yellow dwarf (charlotte), Teeny tiny huge (kay)
  - Dark matter:** Matter and dark matter (er), The darkness (jane), Blackholes (alastair), Plazzies (marissa)
  - Other Topics:** Universe (evelyn), test (erica), Sun vs global warming (marissa), Water (charlotte), Gas giant? :-), Confused (jamie), COOL STUFF!!!!!!!!!!!! (jude), long? (marissa), Why the planets orbit faster when they are closer to the sun (steffany), Why dose the sun not explode (josh), Supernova materials (charlotte), Do stars move (simone), Facts about the sun (simone)
- Handwritten Tags:** Galaxies, gravity, Nebulas, Moons, Stars, Dark matter, Hands.
- Buttons:** Add Tag (lower left), Pause, Tagging, Prop.

Figure 38. Ben's Common Board (IWB) display, with the CK system in Brainstorm state. The community has clustered white note icons into topic groupings and labeled the clusters with socially-negotiated tag words, which will be entered into CK by the teacher using the "Add Tag" button (lower left).

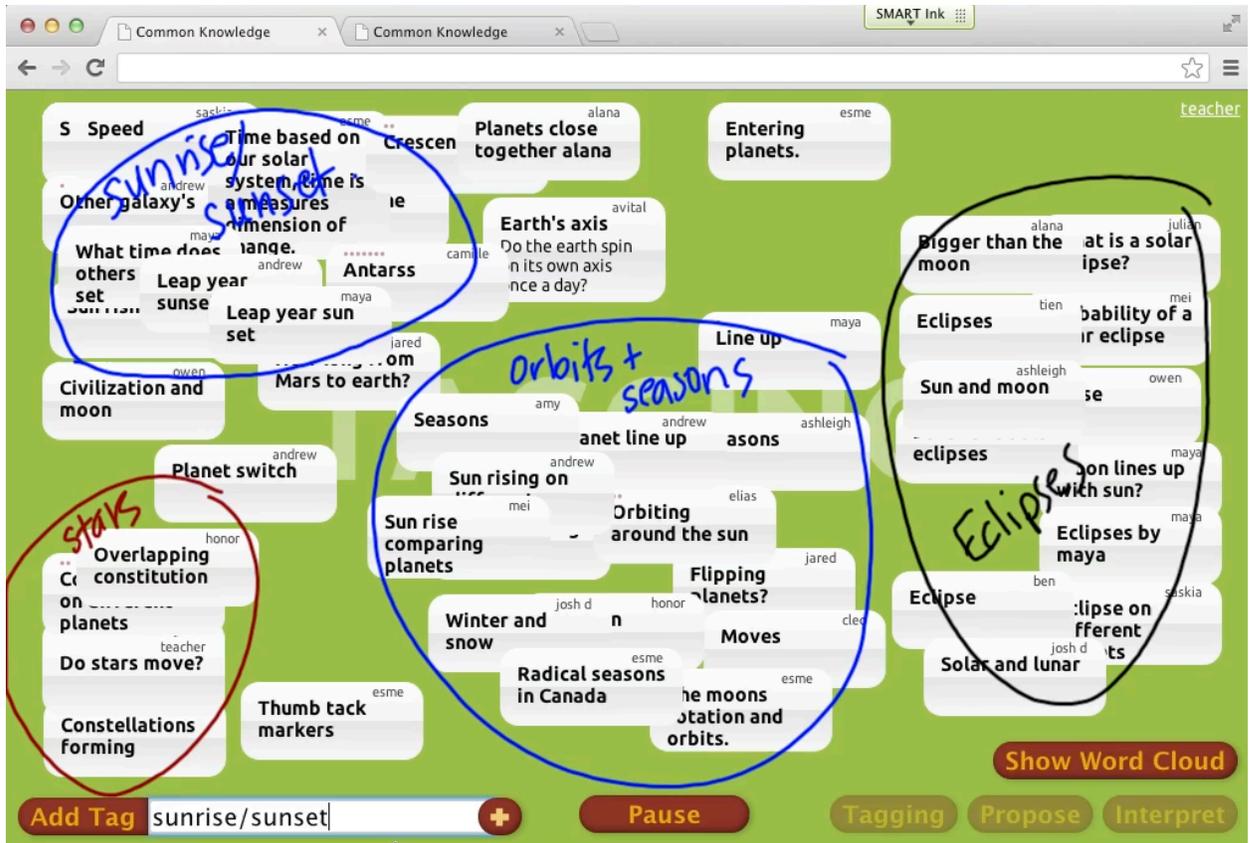


Figure 39. Jen’s Common Board (IWB) display, during social negotiation of tags in the Brainstorm phase. Jen is in the process of inputting the community’s first tag, “sunrise/sunset”, which will then be used by students in a subsequent tagging activity.

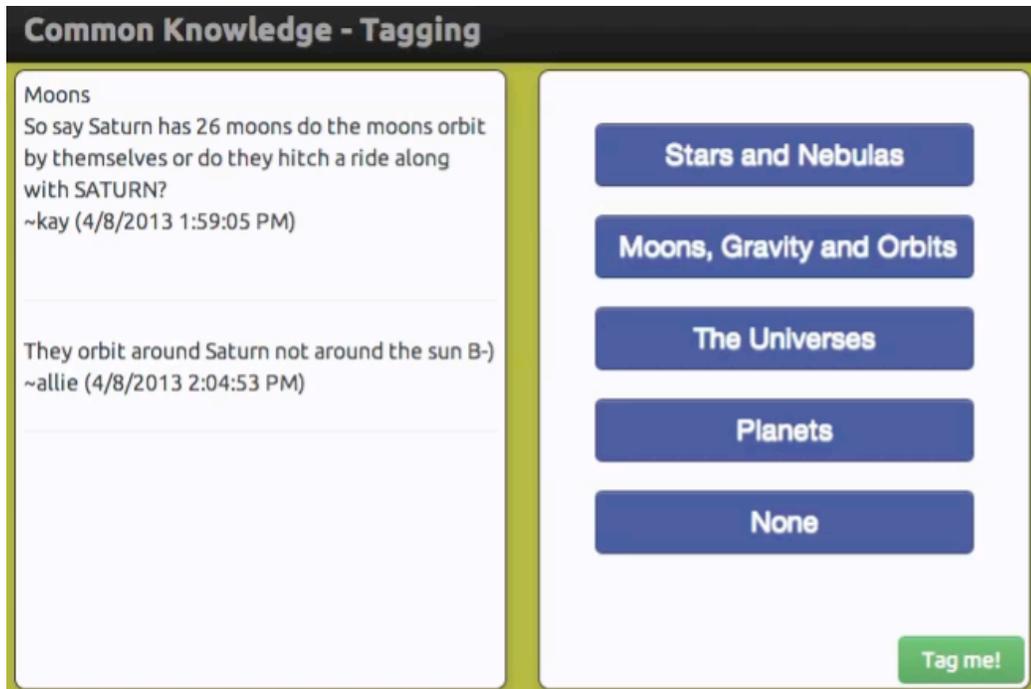
Table 25 lists each class’ socially-negotiated tags. The teachers were aware that students’ negotiated tags might not align perfectly with the three core topics (gravity, scale, and nested systems), but they anticipated reasonable alignment given that the introductory activities had been closely connected to the core topics. Thus, while teachers did not make an explicit effort to map student categories to the core topics, they were satisfied that there was suitable alignment with the community’s brainstorm themes.

Table 25  
Each Community’s Socially-Negotiated Tags

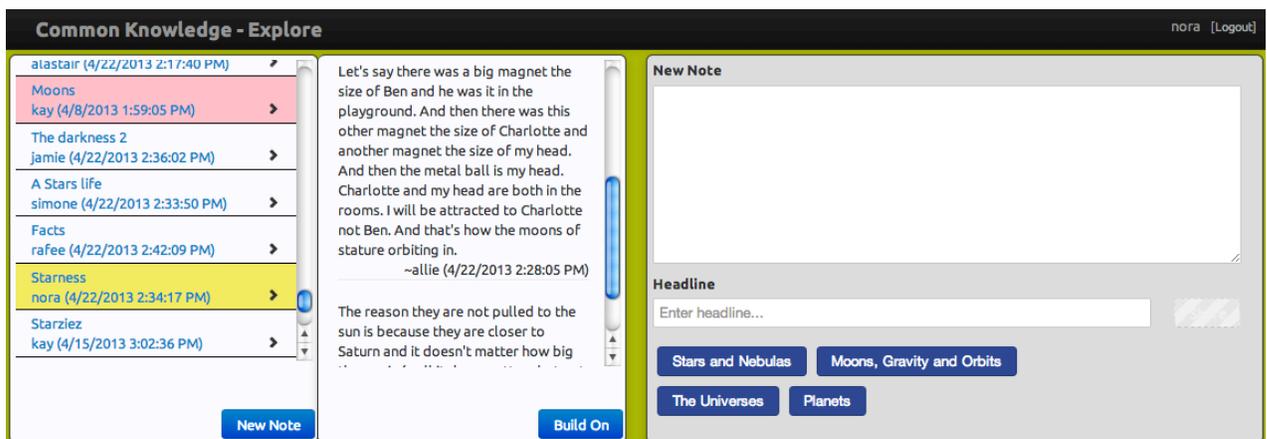
Socially-Negotiated Tags	
Brad’s Class	Jen’s Class

Stars & Nebulas	Eclipses
Moons, Gravity, and Orbits	Orbits & Seasons
The Universe	Sunrise/Sunset
Planets	Stars

From the IWB, the teachers could input the tags by tapping the “Add tag” button. Then, when all tags had been agreed upon and added, the teacher tapped the “Tagging” button (lower right corner, as seen in Figure 39) to initiate a unique note distribution process where each student tablet received a note to be tagged (see Figure 40). Once the student had tagged and submitted the note, she would receive another note to tag (never one that she had created). In this way, students continued receiving and tagging notes until there were no more notes remaining. We referred to this process as “bucket-tagging” – as if notes had been selected one at a time from a bucket, and distributed to students. After all notes had been tagged, students were still able to contribute new Brainstorm notes, which they self-tagged (Figure 41). The Common Board now showed the notes with connection lines to their corresponding tag nodes (see Figure 42). The orange tag nodes on the IWB also served as touchable note filters, such that pressing a tag would toggle its corresponding notes between active and translucent (i.e., inactive) views.



*Figure 40.* CK v.3 tablet interface during bucket-tagging. Students received randomly selected notes (and any associated build-ons), which appeared one at a time in the reading panel on the left. The student could tag the note with any of the four tags, or a fifth “None” tag (if no tags were relevant), and then tap the “Tag me” button. Once tagged, another note would appear.



*Figure 41.* CK v.3 individual/student tablet interface. The left panel is an index of the community’s CK notes. Yellow index items indicate to the student user that the note was one they had authored themselves. Pink index items indicate the note currently being displayed in the centre reading panel. The student could compose a new note in the right panel with a required title (“headline”) and at least one tag. Students could also build-on any note they read.



At the onset of the *Propose* phase, the classroom was divided into 4 table groupings – one for each of the four main topic tags. Students were instructed to sit at the table (topic) they were the most interested in, and to select the topic corresponding to their table group. Students were always free to join a different interest group (i.e., and move to that table) by logging out of their tablet, logging back in, and selecting a different tag/topic. Once students had selected their topic of interest, only the Brainstorm notes that had been tagged with that topic appeared on their tablet. Working at their interest group tables, students talked with peers, reading through the Brainstorm notes to come up with ideas for proposals that could respond to the general topic and specific questions raised in the brainstorm.

Students authored proposal notes, which consisted of a basic idea or topic for further inquiry, and a justification for the proposed activity (Figure 43). Students could propose either (1) a “research” project that would involve gathering information from secondary sources, or (2) an “experiment” that they could perform to test their hypotheses and theories. Experiments could involve the collection of primary data, or the exploration of a digital astronomy simulation, such as Stellarium (<http://www.stellarium.org>). After discussing their ideas with peers in their table group, students authored and published their proposals, which appeared on all tablets and on the IWB Common Board, colour-coded by the corresponding tag colour, and connected by a line to the relevant tag node (see Figure 44). From their tablets, students could read proposals contributed by any of the topic groups. When reading any particular proposal, if a student thought that it would help to advance the community’s knowledge, s/he could indicate this by tapping the “Promising Inquiry Icon” (a light bulb icon) to cast their vote. On the IWB, each Proposal appeared as a thumbnail, including a light bulb icon with a number inside showing the total tally of all votes cast for that proposal (Figure 44).

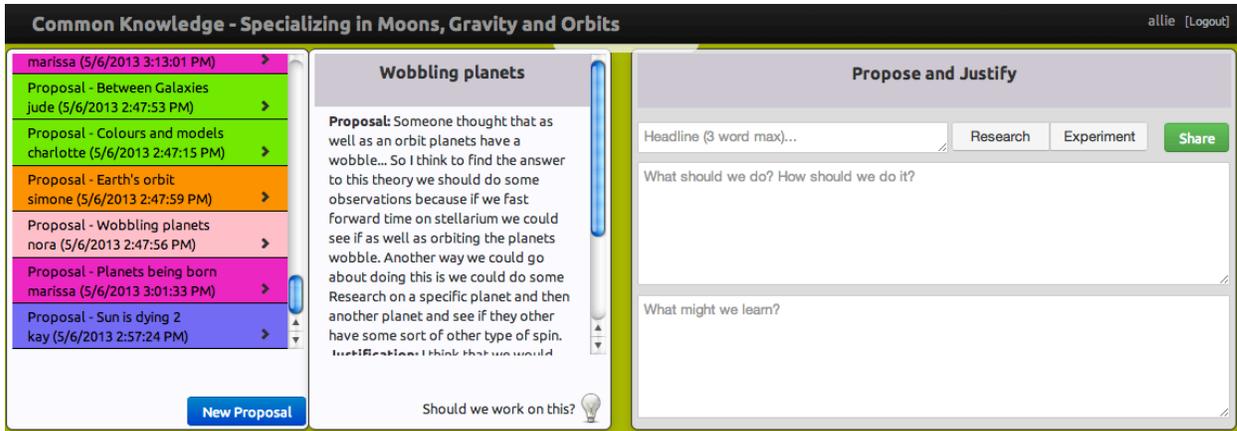


Figure 43. CK v.3 tablet interface for reading and composing “Proposal notes”. The left panel lists all contributed proposals, colour-coded by tag. The middle panel displays the currently selected Proposal note (for reading) – students press the “Should we work on this?” Promising Inquiry (light bulb) icon if they think the proposal is worthwhile for the community to pursue. Students use the right panel to compose a new Proposal note.



*Figure 44.* CK v.3 Common Board (IWB) in the Proposal phase, for Jen’s class. Proposal note icons contain a Promising Inquiry (light bulb) icon showing the number of votes the proposal received for being a worthwhile investigation.

### ***Phase 3: Investigate***

The third phase of inquiry, *Investigate*, was again initiated when teachers simply pressed the “Investigate” button on the CK Common Board, once they had concluded that a sufficient number of proposals had been produced to motivate student inquiry. At this point, each table group received its own CK Topic Board, which was similar to the main Common Board (on the IWB), without the orchestrational tools used by teachers such as the “Pause” or phase-switching buttons. Each Topic Board displayed its topic name prominently in the centre of the screen, and its background colour corresponded with its topic (Figure 46). The CK Topic Boards served to reinforce and support the spatial distribution of topics around the classroom, with a different topic for each table group, displayed on a large computer monitor located at each table. These CK Topic Boards served as shared public displays, dedicated to capturing and representing an interest group’s ideas and activities, as their investigation notes grew around the proposals (Figure 45). At the front of the classroom, the Common Board synthesized the content from all four Topic Boards, colour-coded by topic (Figure 49), including all previous functionality (i.e., of clicking notes to open and close them, and filtering by topic).

**Common Knowledge - Investigating Moons, Gravity and Orbits**

Proposal - Moon orbits nora (5/6/2013 3:09:36 PM)	>
Proposal - Earth's orbit simone (5/6/2013 2:47:59 PM)	>
Proposal - Wobbling planets nora (5/6/2013 2:47:56 PM)	>
Inquiry - Big moons (5/9/2013 11:40:59 AM)	>
Inquiry - Orbits of satellites (5/9/2013 11:53:04 AM)	>
Inquiry - Black hole model (5/9/2013 11:55:42 AM)	>
Inquiry - Orbits	>

**Wobbling planets**

**Proposal:** Someone thought that as well as an orbit planets have a wobble... So I think to find the answer to this theory we should do some observations because if we fast forward time on stellarium we could see if as well as orbiting the planets wobble. Another way we could go about doing this is we could do some Research on a specific planet and then another planet and see if they other have some sort of other type of spin.

**Justification:** I think that we would

[New Proposal](#) [New Inquiry](#) [New Experiment](#)

**New Experiment about Wobbling planets**

Headline... [Share](#)

What question are you investigating?

Make an educated guess about how this works!

Figure 45. The CK v.3 tablet interface for the *Investigate* phase. Here, the student is initiating a “New Experiment” note, in response to the “Wobbling planets” proposal.



Figure 46. One of four CK v.3 Topic Boards that supported “The Universes” group work in a classroom during the *Propose* phase. Proposal icons contain an Inquiry (light bulb) icon showing the number of votes the proposal received for being a worthwhile investigation, and are linked to any corresponding Inquiry Reports or Experiment Reports (indicated in the top-left of the report’s thumbnail).

By design, the Brainstorm notes were no longer accessible from neither tablets nor the IWB during the *Investigate* phase. The intention of removing Brainstorm notes was to reduce clutter and distraction, and to motivate progress.

Students continued to group themselves spontaneously according to their topic of interest by logging into any of the four interest topics on the CK system, at which point they would access topic-specific proposals. As students read the proposal notes on their tablets, they were given two possible ways to respond: (1) an Inquiry Report, which would summarize their findings from reading reference materials or other resources, or (2) an Experiment Report, which would summarize the results and outcomes from an experimental investigation they had

performed (see Figure 45). Students could also initiate new proposals during this *Investigate* phase – in acknowledgement that inquiry would likely give rise to further ideas and directions.

The CK Topic Boards represented the progress of each group, displaying all proposals visually linked to their corresponding Investigate reports. A word cloud was accessible as well, to serve as a visualization of the ideas emerging within each interest group’s investigations. It was thought that both students and the teacher (who would circulate amongst the topic groups) could make use of these representations.

Finally, we added the notion of a “knowledge walk” to the script, where students could leave their table group and visit different tables, talking with peers, and reading their notes and reports – either by opening them on the topic board or by logging into that group from their own tablet. As student investigations gained momentum or came to a plateau, the teacher could prompt them to walk around the room and survey other group’s materials. If a student felt that a Report from another group connected conceptually with their own investigation, s/he could indicate this by pressing the Connection icon on the note, which incremented its Connection score (Figures 47 and 48). On the CK Common Board (i.e., at the front of the room), all proposals and reports were displayed (colour coded by topic) including the overall Knowledge Connection scores, which appeared as a number inside a double-headed arrow on the note/report’s thumbnail icon (see Figure 49).

**Common Knowledge - Investigating Moons, Gravity and Orbits**

Proposal - Moon orbits nora (5/6/2013 3:09:36 PM) >	<h3 style="text-align: center;">Big moons</h3> <p><b>Type:</b> inquiry</p> <p><b>New Information:</b> A lot of people think that moons are smaller than planets, that is not true. There are only a few large moons in the solar system, they are larger than Mercury and Pluto. Some of these moons have volcanoes, atmosphere's and liquid water ocean's. Moons are moons because they circle around planets, planets are planets because they circle around the sun. Moons can be ignored, which is very</p> <p>This connects to another idea we've worked on </p>
Proposal - Moony moon moon allie (5/13/2013 2:26:54 PM) >	
Proposal - Earth's orbit simone (5/6/2013 2:47:59 PM) >	
Proposal - Wobbling planets nora (5/6/2013 2:47:56 PM) >	
Inquiry - Big moons (5/9/2013 11:40:59 AM) >	
Inquiry - Orbits of satellites (5/9/2013 11:53:04 AM) >	
Inquiry - Black hole model	

[New Proposal](#)

*Figure 47.* CK v.3 tablet interface in the Investigate phase. The left panel lists all Proposals, Inquiry Reports, and Experiment Reports; for the “Moons, Gravity and Orbits” interest group. The right panel displays the selected note. A student may indicate the findings in this Inquiry Report connect with their own investigations by voting with the “This connects to another idea we’ve worked on” Knowledge Connection icon (double-headed arrow).



*Figure 49.* CK v.3 Common Board in the *Investigate* phase, showing all Proposals and Investigation Reports from the four interest groups, colour-coded by interest topic. Where double-headed arrows indicate the number of students who saw conceptual connections with other student investigations.

The design of this iteration of the CK technology differed from the previous version, as it served not only to collect and organize student notes and scaffold teacher-guided discourse, but also added explicit supports for the orchestration of inquiry progression, including a division of the class into distinct topic groups with their own common boards and representations. It also provided the teacher with specific scaffolds (i.e., the Tagging, Propose, and Investigate buttons) to advance CK from one inquiry phase to the next. We also introduced the use of intelligent agents to help with the sorting, distribution and tagging of notes, and word clouds on all public displays to offer a quick view of the semantic contents of any CK space. Students were supported in making conceptual connections between Proposals and Reports within and between the topic categories. These are substantive design revisions that responded to issues identified previously, and also sought to explore the open question about how to help teachers coordinate the progression from one inquiry phase to the next.

### **CK Version 3 Design: Activity Script**

This section reviews the designed activity sequence (i.e., *Brainstorm*, *Propose* and *Investigate* phases). The presentation will be brief, as the previous section already reviewed those activities because they were so interwoven with the technology design. In the previous iterations of CK, teachers were wholly responsible for moving the class from one inquiry phase and the next, and CK did not contain any specific scaffolds for such orchestration. In this iteration, the teacher still needed to choose the time to orchestrate a shift, but the transitions were

fully specified and coordinated by the CK technology environment. For example, midway through the first Brainstorming phase, there was a “Tagging” button on the IWB (Figure 36) that, when pushed, interrupted student brainstorming to place all student tablets into an entirely new technology state, where they would receive notes one at a time from the CK system, for the bucket tagging activity. In this way, the CK system was designed to facilitate the orchestration of the *Brainstorm* phase, and ultimately the progression into the *Proposal* phase, as the tagged notes would then serve as a foundation for students’ proposal writing.

Prior iterations of CK had revealed a Reflect-Refocus-Release (3R) orchestration pattern, in which teachers used students’ ideas captured in CK notes to spur episodes of *reflective* community discussion, scaffolding the community to further develop those ideas, examine the state of their progress, and consider promising new directions. This would culminate in a set of instructions issued by the teacher to *refocus* the community’s subsequent inquiry activities on matters to address the knowledge gaps or new directions identified in the reflective discussion. Analysis of iteration two enactment data (Chapter 4) showed that the teachers’ refocusing instructions have strong bearing on students’ subsequent CK note contributions, as demonstrated by the high congruency scores of CK notes with the refocusing instruction. Once the teacher has issued the refocus instructions, s/he then *releases* the community to independently pursue their inquiry in the CK environment. As students contribute CK notes during this Release phase, the teacher monitors (from the IWB) the incoming notes while circulating among students to monitor their progress, answer their questions, and challenge any misconceptions. Continuing the cycle, the teacher would eventually decide to capture the community again for a new reflective discussion, based on some determination of a problem, opportunity, or plateau in their current inquiry.

In designing this new iteration of CK, we expected to see a similar orchestration cycle, punctuated by the major transitions between inquiry phases. While our script had defined certain transition points, in which teachers would guide the community from one inquiry phase to another, the teachers would ultimately decide when these transitions should occur, based on their formative assessment of students' conceptual understandings, productivity, and motivation level. One open question stemming from this design is concerned with how teachers decide when is the right time to make such a transition, and how they could support these transitions with discourse, using the CK content and representations. In iteration 2, such transitions relied on carefully crafted conceptual segues that drew upon students' knowledge and inquiry concerning the WallCology content (e.g., habitats, organisms, lifecycles, etc.). In this third iteration, there would be no structured content by which teachers could gauge progress (i.e., no Embedded Phenomenon with well defined elements and conceptual connections) – only open-ended student proposals and investigations. Hence, the activity sequence in this iteration, while more structured (i.e., including several distinct phases) was also more open ended and reliant on teachers' interpretation of the CK content, to guide their discourse.

While it would be reasonable to expect similar 3R activity cycles, I had no hypotheses about how the teacher would lead or support the progress between inquiry phases. In other words, now that some of the orchestrational load of the inquiry progression was being accommodated by CK, the teacher would have new opportunities and obligations (e.g., to help move the class into a position where it would be ready for a major phase change).

### **CK Version 3 Design: Expected Discourse Patterns**

Because this iteration had included some very large changes – removing the structured domain of inquiry (i.e., the Embedded Phenomenon), and emphasizing a scripted sequence of

inquiry phases – it is important to maintain an open position regarding what forms of discourse might occur, and how these might reflect problems or opportunities with this more structural approach to CK. In other words, it is not reasonable to expect that teachers would engage in the same discourse patterns in this iteration, since the technology and activity structures were quite different. Thus, while the basic 3R pattern seemed likely (i.e., at the time of design) the specific patterns identified in iteration 2 would likely shift in response to these new conditions, where teacher led discourse would be required to respond to new problems that had been introduced, or to take advantage of new opportunities.

Previous CK enactments revealed four orientations of teacher-guided discourse: Individual Reflection (IR), Teacher Reflection (TR), Community Reflection (CR), and Community Instruction (CI). Analysis of the iteration two (WallCology) enactment in Chapter 4 provided further detail about the specific functions of teacher comments within these orientations, including various means of revoicing student ideas, empowering students within the community discourse, and raising awareness of patterns or progressions within the inquiry. This coding helped to clarify the role played by CK in providing the teacher with access to student ideas via the Common Board to support the catch-and-release activity pattern. An ongoing priority for CK is the design of features that support the teacher – and the classroom at large – to access the community knowledge, and put that knowledge to work in furthering their inquiry. Early versions of CK provided such access simply by representing all notes in a common location, so that teachers and/or students can create their own clusters and teachers could guide discussion among the community. But such support may be further enhanced through new technology features such as tags, votes, or connections that allow patterns (including knowledge gaps or conflicts) to become more salient and accessible for discussion.

The present iteration of CK included some additional technological features to support the community's progression through the script. The distribution of all notes to all students for tagging served to engage students in reading peers' notes and consider how best to categorize the ideas contained within. Similarly, distinct note formats for proposals was introduced to encourage the progression of students' brainstormed ideas toward investigations, whereupon the separation of topics into separate topic-driven knowledge bases would allow focus of the investigations. The goal of these new elements was to facilitate inquiry, but we did not know if they would be successful, and – if they did succeed – what impact they might have on the nature of classroom discourse.

Such features could potentially be too coercive, and actually restrict inquiry, reminiscent of Dillenbourg's (2002) notion of "overscripting." Such coercive orchestrational elements run the risk of disempowering the teacher and restricting the freedom of student ideas, ultimately resulting in less engaging or productive inquiry. In any case, adding such structural features into CK would place new burdens on the teacher for ensuring students' engagement and success. Clearly, this would entail some form of strategic discourse, although it was an open question at the time of design what such discourse might look like.

Because CK was being used with the same two teachers, and because it was still a notes-based learning environment, we assumed that the 3R orchestration cycle and the four discourse orientations would be present. However, because of the changes in the overall activity system, teacher-guided discourse would need to serve different goals or purposes, requiring more effort or attention in some aspects, and perhaps less in others. Given the technologically abrupt phase transitions, teachers might feel a greater need to ensure that the widest range of ideas had been addressed, or that all ideas are acknowledged and examined for misconceptions. In sum, taking

away the need for teachers to coordinate the transitions between phases (i.e., by having CK assume this burden) might remove the need for some kinds of discourse and add opportunity for others.

Hence, the enactment analysis for this iteration must examine the interacting elements of the activity system: (1) whether the technology worked as designed; (2) what was the actual sequence of activities enacted; and (3) what forms of discourse occurred. We must acknowledge that if the technology or activity designs were somehow flawed or ineffective, the teacher-guided discourse would be serving to repair those shortcomings. Thus, whatever discourse patterns were observed would reflect not only the nature of successful teacher orchestration, but also their repair of or response to weaknesses or flaws in our design. The enactment analysis must therefore be a formative effort to identify activity and discourse patterns relating to the enactment this version of the CK system as an orchestrational environment. As such, it will focus more on the flow and sequencing of activities, and the role of discourse, more than on the finer-grained discourse analysis for scaffolds, that characterized Iteration 2.

### **CK Version 3: Enactment Analysis**

Iteration 3 enactment analysis will focus on three classroom sessions for each of the two teachers: one session per inquiry phase, selected according to the richness of CK-driven community discussion, as well as CK note contribution. In some cases, this required using segments that spanned two class sessions (i.e., the latter segment of one class session and an early segment of a subsequent session), to capture a coherent snapshot of a community's inquiry activity within that phase. The goal in selecting these class sessions was to reveal the interplay between teachers' use of students' written ideas (via CK) and students' spoken ideas (during

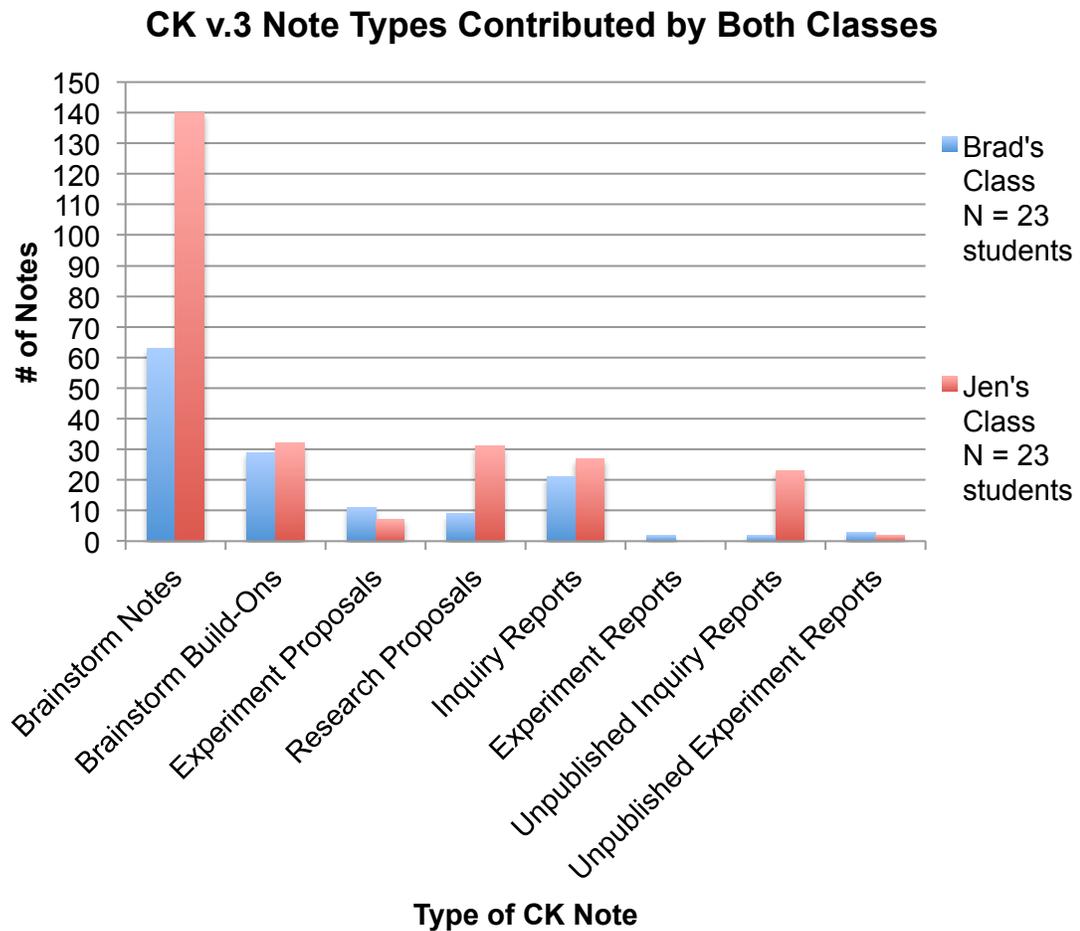
community discussion), and how these were employed by teachers to scaffold a community's inquiry.

Pea (1994) described the notion of “transformative communication” in which new ways of thinking and learning are appropriated by a community through discourse. By supporting students in their inquiry, collecting their ideas and encouraging collective reflection and progress, CK can provide a sense of agency to students, supporting transformative communication through “dialogic activity structures” (e.g., “action negotiation dialogues”, “student questioning dialogues”, and “action feedback dialogues” - Polman, 2004) such as those explored in the previous iteration. Thus, one area of particular interest to the analysis of this third iteration is the potential for CK technology to make knowledge more accessible for further idea refinement during community discussion, and to foster knowledge convergence as a means of driving inquiry progression (i.e., through the scripted phases of a curriculum unit).

### **CK Version 3 Enactment: Technology Outcomes**

In iteration 3, students continued to use the CK tablet interface as a means of adding notes, and to tag notes with relevant semantic features. Figure 50 summarizes the quantity of each note type contributed by Brad's and Jen's students over the duration of the Astronomy unit. In total, Brad's class contributed 135 notes and 5 “unpublished” reports (i.e., that were authored by students, but never “published” for the community). Unpublished notes sometimes happened as a consequence of students' hasty logging out at the end of a period (i.e., forgetting to hit “submit”), or else potentially from technology issues (i.e., where they may have tapped “Submit”, then logged out, and the note did not get published). Jen's class contributed 237 notes and 25 unpublished Reports. It is worthwhile to note that Jen's students continued to use CK for approximately two weeks beyond this research project's timeframe, for their student-driven

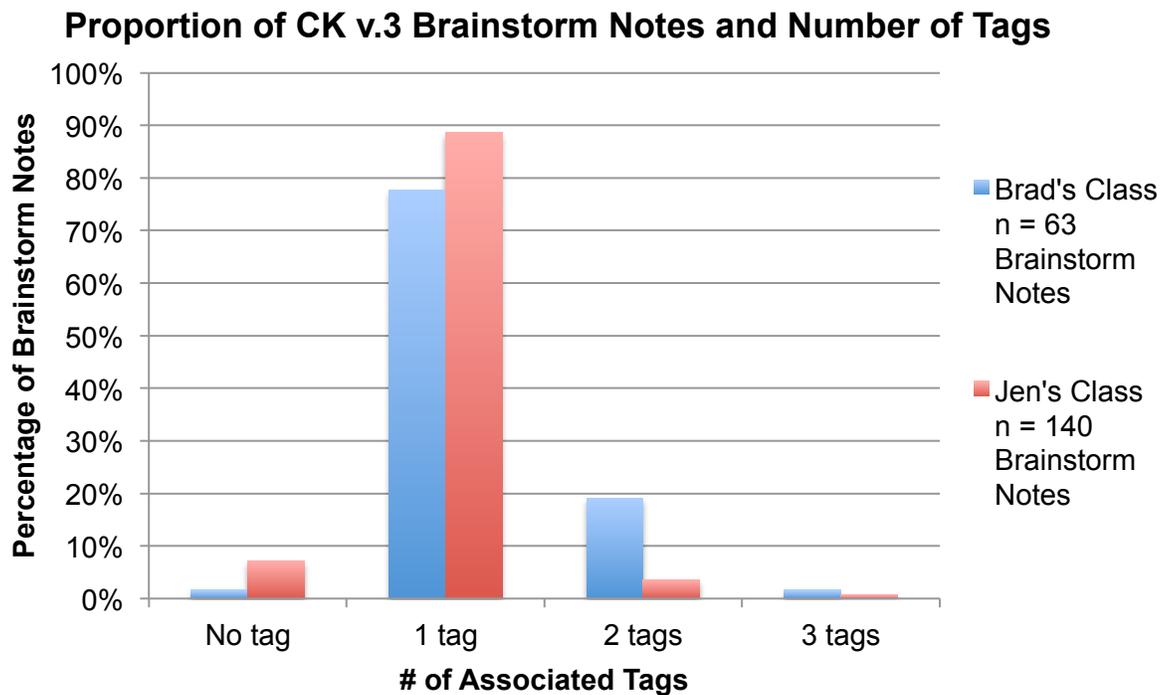
investigations. During this time, Jen’s students contributed 16 of their 38 Proposals, 16 of their 27 published Reports, and 24 of their 25 unpublished Reports. Analyses in this chapter will track the published and unpublished notes separately, occasionally pooling them together where it is sensible to do so.



*Figure 50.* The quantity of types of notes that were contributed by Brad’s and Jen’s classes over the duration of the Astronomy unit, using Common Knowledge.

Midway through the *Brainstorm* phase, both classes socially-negotiated four tags (“categories”) which they felt conceptually captured their collective knowledge. In the *Proposal* phase, these tags were elevated to the status of topics, structurally organizing not only the

community knowledge base, but also the inquiry trajectories and their corresponding collaborative groupings. Figure 51 shows the number of tags associated with Brainstorm notes for both classes. Brainstorms that were deemed by learners during bucket-tagging not to adequately relate to any of the four tags were categorized as “No tag”. After the completion of bucket-tagging, CK made it mandatory for students to self-tag all new Brainstorm notes with a minimum of one tag. Because the categories were so distinct (e.g., “gravity” vs. “galaxies”), it is not surprising that the majority of Brainstorm notes received only one tag.

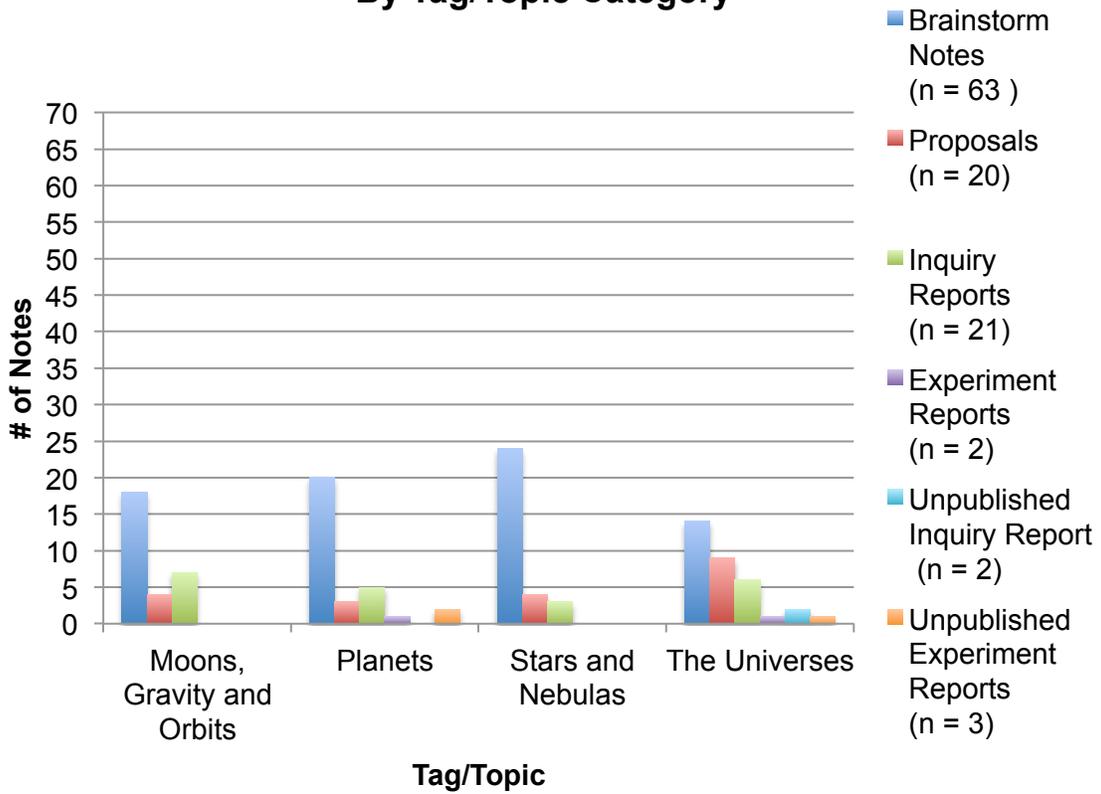


*Figure 51.* The proportion of phase 1 Brainstorm notes and their tag associations.

Figure 52 shows the quantity and type of note associated with each class’ four topics. Brainstorm notes were the most prevalent, as students had been encouraged to submit multiple notes, seeking a diversity of ideas (Scardamalia, 2002). There were generally fewer proposal

notes than Brainstorm notes, within any category, as proposals were meant to be more substantive and generative of inquiry. Report notes (“Experiment” and “Inquiry”) were added as students addressed the proposals during the *Investigate* phase, with some topics garnering numerous reports, and others receiving little or no attention.

**CK v.3 Note Types Contributed by Brad's Class,  
By Tag/Topic Category**



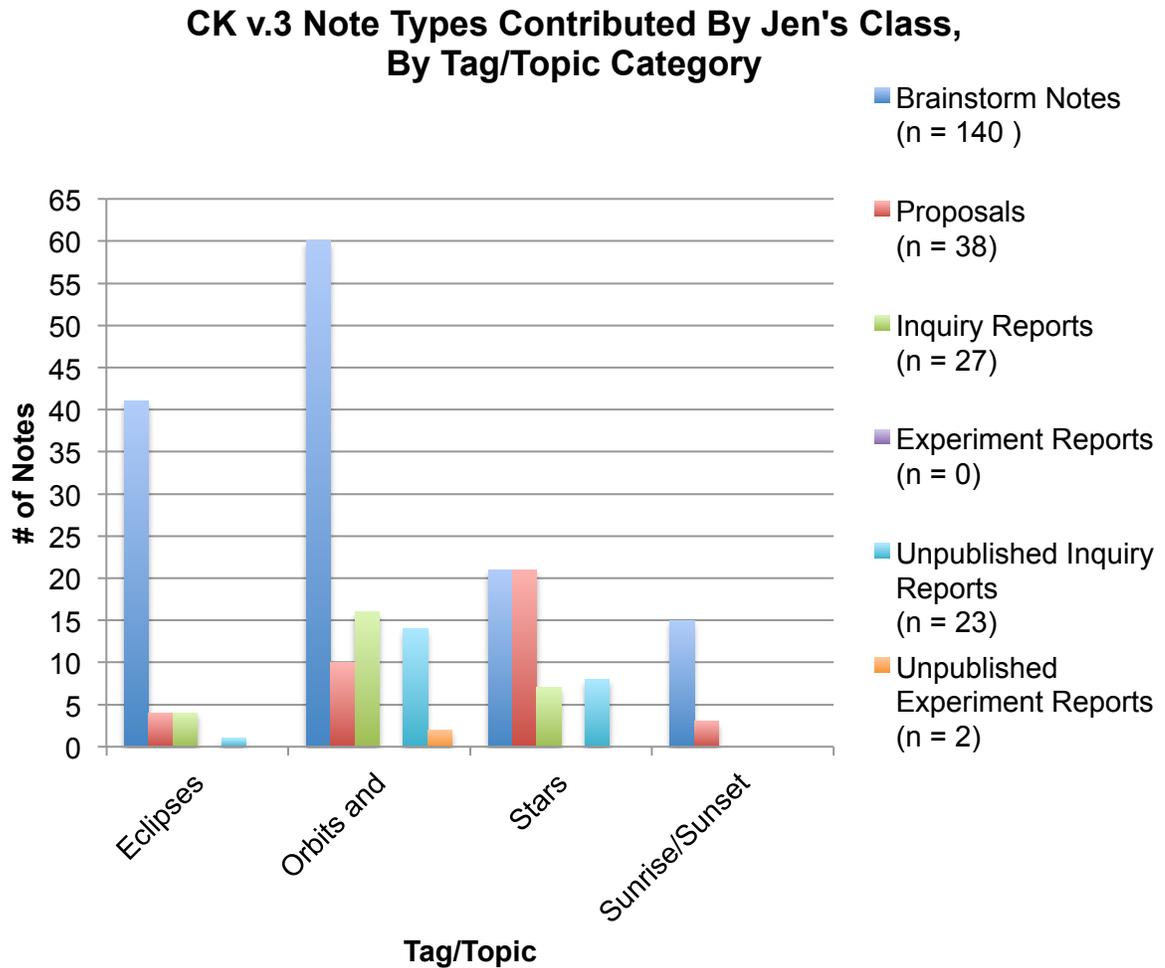


Figure 52. Types of notes contributed by each class, for each tag topic.

A closer look at the content of the notes can provide some insight about whether the classroom knowledge community was supported in accessing and applying knowledge from one inquiry phase to the next. To examine whether ideas from phase 1 Brainstorm notes informed or gave rise phase 2 Proposals, each proposal note was scored for its congruity with the Brainstorm notes, using a Knowledge Integration rubric (Lee & Liu, 2010; Liu, Lee, Hofstetter, & Linn, 2008). Similarly, phase 3 Reports were scored for congruity with their corresponding proposals to determine if the questions and ideas defined in the proposal notes underwent further development during the *Investigate* phase. Unpublished reports were grouped with published

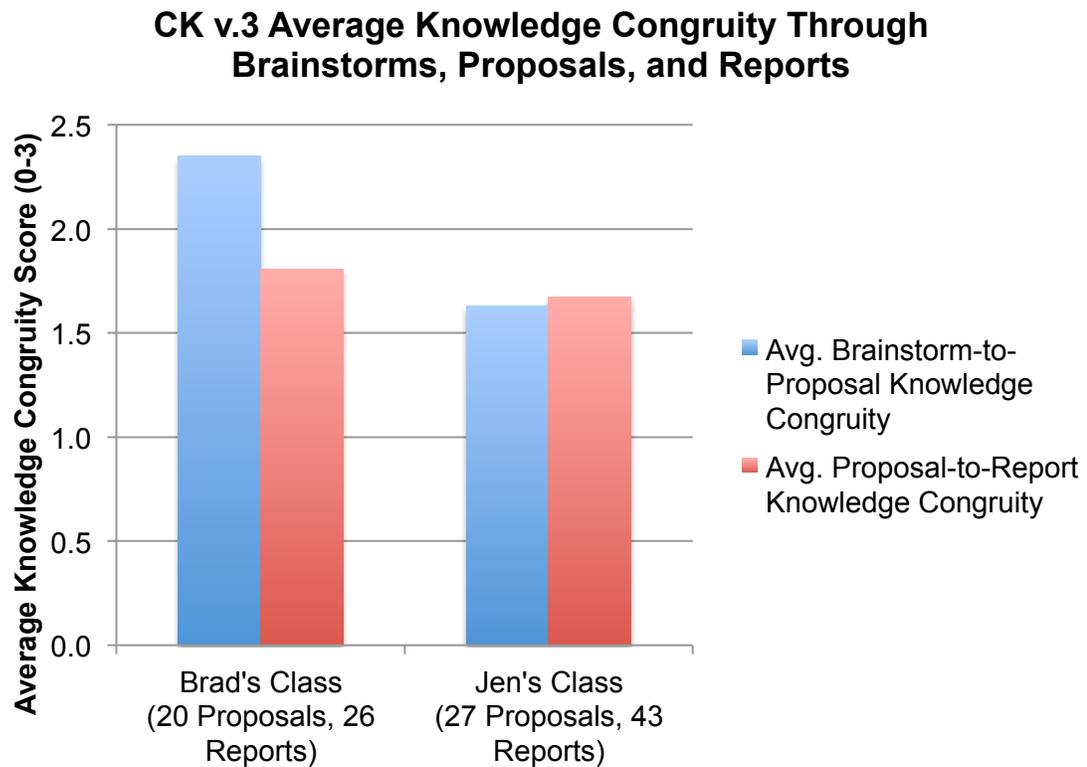
Reports in these analyses, in recognition of students' investigations as defined in corresponding Proposals. In cases where multiple unpublished reports existed, only the most complete version was scored. Table 26 defines both scoring rubrics.

Table 26  
*Knowledge Convergence and Knowledge Congruity Scoring Rubrics*

<b>Brainstorm-to-Proposal Knowledge Congruity Scoring</b>	
3	Direct and meaningful reference to more than one Brainstorm note.
2	Direct and meaningful reference to one Brainstorm note.
1	Some reference to at least one Brainstorm note.
0	No reference to any Brainstorm note.
<b>Proposal-to-Report Knowledge Congruity Scoring</b>	
3	Direct and meaningful reference to corresponding/parent Proposal, extending the inquiry beyond what was defined in the Proposal.
2	Direct and meaningful reference to corresponding/parent Proposal.
1	Some reference to corresponding/parent Proposal.
0	No reference to corresponding/parent Proposal.

Figure 53 summarizes the average knowledge congruity scores for both classes. First, students in both classes scored quite well, with average scores above 1.5, suggesting that proposals were indeed inspired by direct reference to Brainstorm notes, and Reports were influenced by the corresponding proposals to which they were linked. Brad's class, for example, showed clear reference to Brainstorm notes in their proposals. Indeed, the mean knowledge congruity scores of Proposals for Brad's class ( $M = 2.35$ ,  $SD = 0.99$ ,  $N = 20$ ) was significantly higher than for Jen's class ( $M = 1.70$ ,  $SD = 1.07$ ,  $N = 27$ ), with  $t(45) = 2.12$ , and  $p = 0.04$ . Reports contributed by students in both classes generally made at least some reference to

corresponding Proposals. However, mean knowledge congruity scores of Reports for Brad's class ( $M = 1.81$ ,  $SD = 0.69$ ,  $N = 26$ ) was not significantly higher than for Jen's class ( $M = 1.67$ ,  $SD = 1.11$ ,  $N = 43$ ), with  $t(67) = 0.55$ , and  $p = 0.58$ . This supports the notion that the ideas generated in brainstorming were instrumental in the creation of proposal notes, which in turn informed the Investigate report notes. Figure 53 summarizes Brainstorms-to-Proposals and Proposals-to-Reports knowledge congruity scoring for both classes. Table 27 summarizes congruity score distributions of knowledge congruity through Brainstorms, Proposals, and Reports; for both classes.



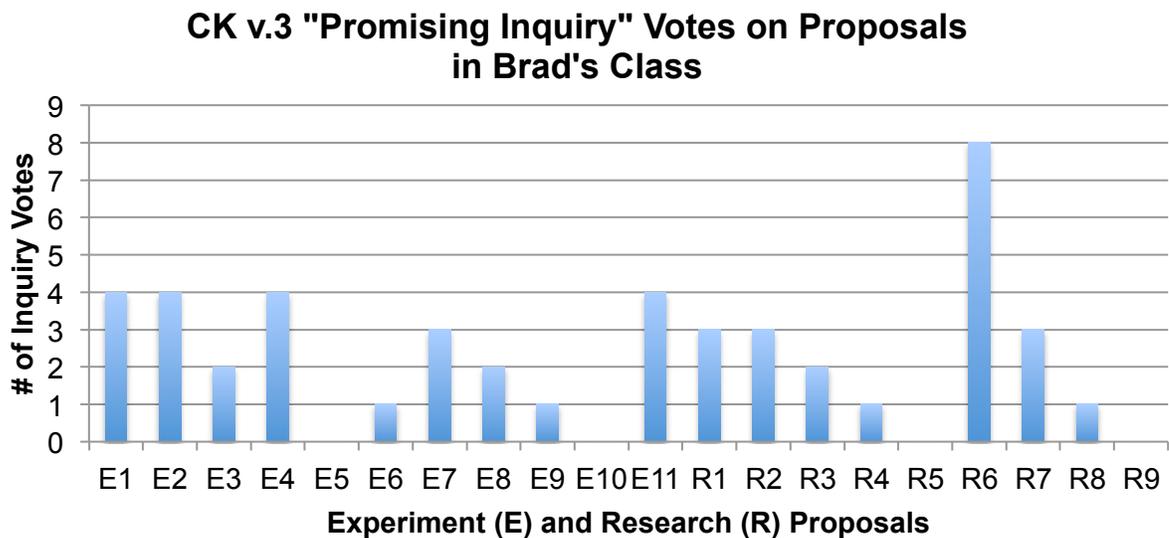
*Figure 53.* Summary of average knowledge congruity scores for both classes. Proposals were scored for their Brainstorm-to-Proposal knowledge congruity (see rubric in Table 26). Reports (including unpublished Reports) were scored for their Proposal-to-Report knowledge congruity (see rubric in Table 26).

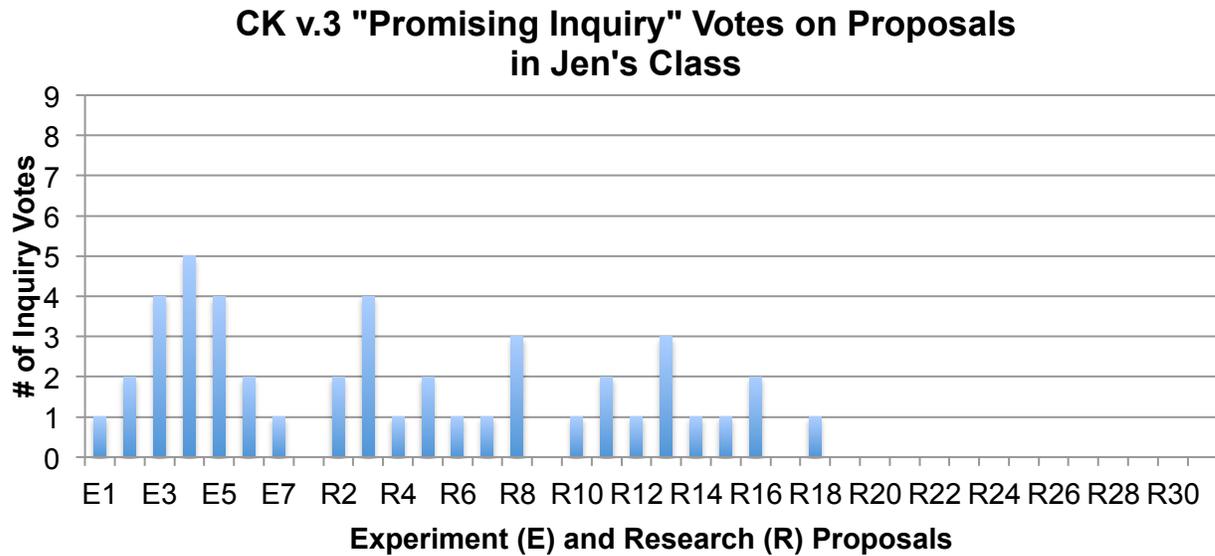
Table 27  
*Summary of Brainstorms-to-Proposals and Proposals-to-Reports Knowledge Congruity*

	<b>Brainstorm-to-Proposal Knowledge Congruity</b>		<b>Proposal-to-Report Knowledge Congruity</b>	
	<b>Brad's Class</b>	<b>Jen's Class</b>	<b>Brad's Class</b>	<b>Jen's Class</b>
# of Notes That Scored 0	2	6	0	9
# of Notes That Scored 1	1	13	9	8
# of Notes That Scored 2	5	8	13	14
# of Notes That Scored 3	12	11	4	12
Total # of Proposals	20	27	N/A	N/A
Total # of Reports	N/A	N/A	26	43
Average Score	2.35	1.70	1.81	1.67

Of the notes contributed by both classes, 20% of proposal notes were independently scored for Brainstorm-to-Proposal knowledge congruity and 20% of Reports were independently scored for Proposal-to-Report knowledge congruity using the rubrics from Table 26 by me and this study's second rater, who is a graduate student in the final stages of a Master's program in "Curriculum Studies and Teacher Development", with four years experience as a preservice teacher educator at a major Canadian university, 12 years experience as an elementary math education consultant at a large urban Canadian public school board, and five years of experience as an elementary classroom teacher in the same school board. For Brainstorm-to-Proposal knowledge congruity, inter-rater agreement was found to be 91.0%, with Cohen's Kappa = 0.84. For Proposal-to-Report knowledge congruity, inter-rater agreement was 80.0%, with Cohen's Kappa = 0.72. Inter-rater disagreements were related to the rater's limited familiarity with the corpus of CK notes, and limited understanding of the preceding inquiry context progression.

Another source of insight about whether knowledge from one phase was accessible as a resource in another phase can be taken from students' voting on the "promisingness" (Chen, Scardamalia, Resendes, et al., 2012) of proposals. Towards the end of the second Propose phase of inquiry, students were instructed to read their peers' Proposals and tap the "Promising Inquiry" icon if they felt that it would be a worthwhile investigation for the community as a whole to learn about (i.e., for themselves to investigate personally, or for anyone in the class to investigate if they so wished). Figure 54 shows the number of Promising Inquiry votes received by Experiment Proposals (E) and Research Proposals (R).





*Figure 54.* The number of Promising Inquiry votes each Experiment Proposal (E) and Research Proposal (R) received from students indicating “Should we work on this?” Total for Brad’s class: 11 Experiment Proposals, 9 Research Proposals, 46 Inquiry Votes on Proposals. Totals for Jen’s class: 7 Experiment Proposals, 31 Research Proposals, 45 Inquiry Votes on Proposals.

It is interesting to see if those proposals that had been voted most promising were also the ones that received the most attention during the Investigate phase. The accumulated votes received by a proposal represents some “knowledge work” done by the community to evaluate the proposal in terms of its attractiveness for inquiry. Did students attend to that knowledge when it came time for them to choose a proposal to work on? Figure 55 shows a scatterplot of the number of notes received by a proposal (y-axis) against the number of votes it received (x-axis) for the two classrooms. A Pearson’s correlation test obtained a marginal significance for Brad, with  $r(18) = 0.40$  ( $p = 0.08$ ), and no significance for Jen, with  $r(36) = -0.02$  ( $p = 0.93$ ). Thus, in Brad’s class, students had some inclination to pursue Proposals that had received more Promising Inquiry votes, whereas in Jen’s class that did not seem to make a difference.

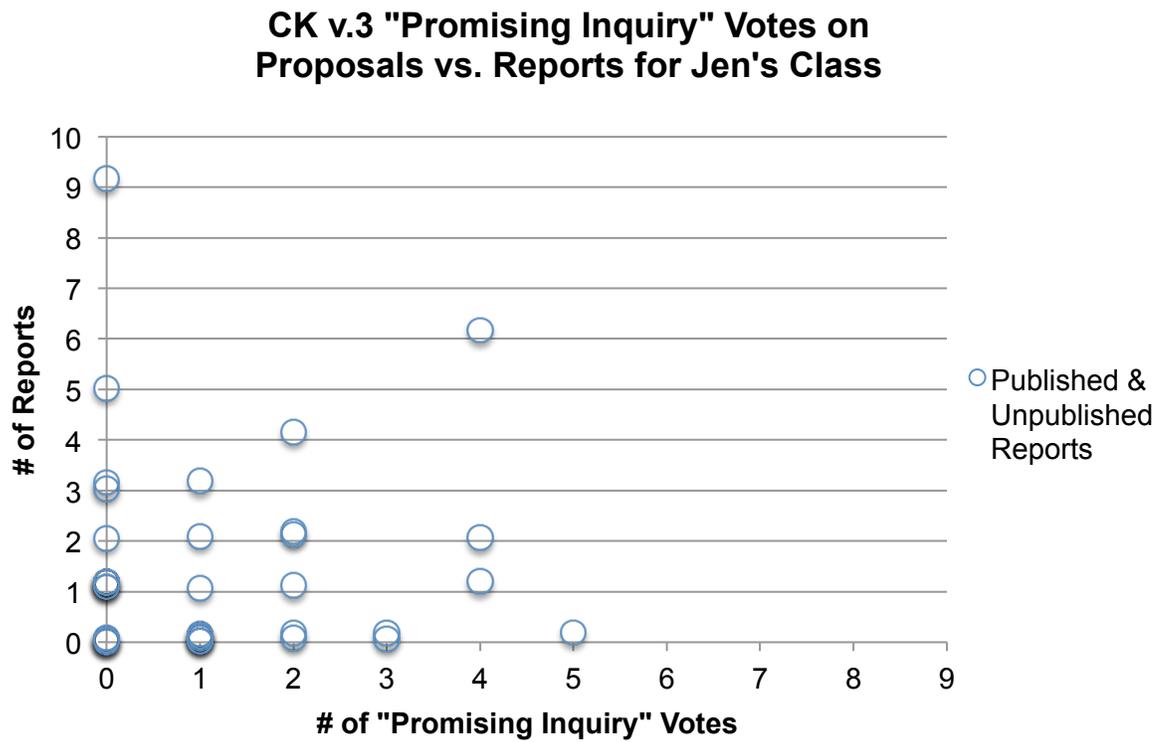
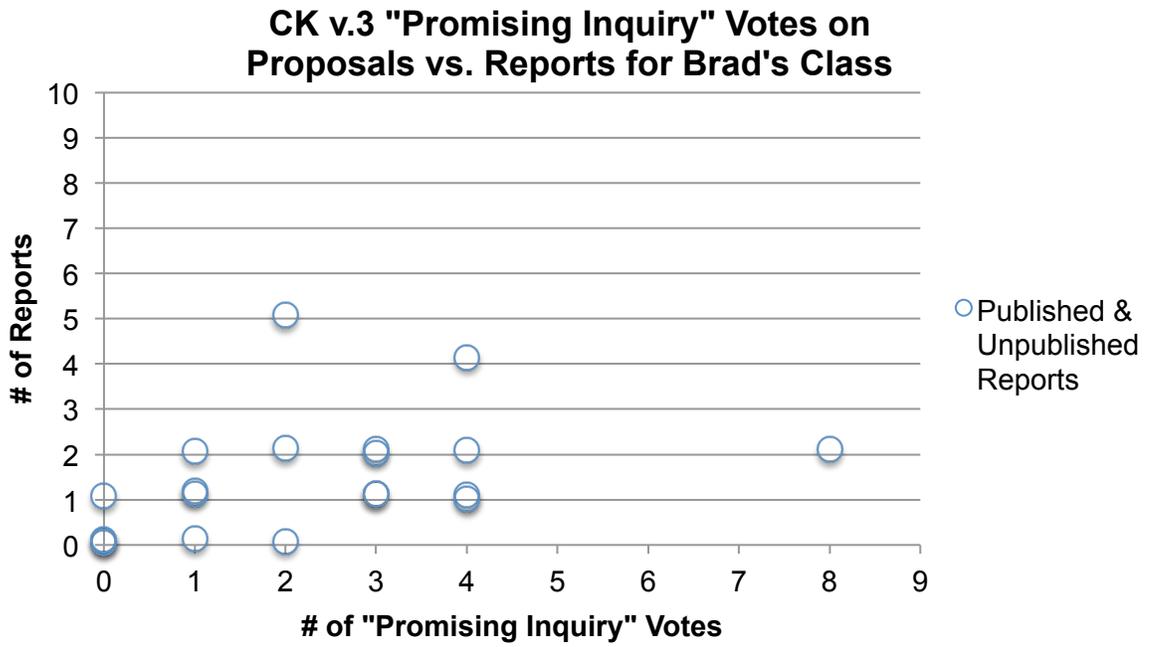
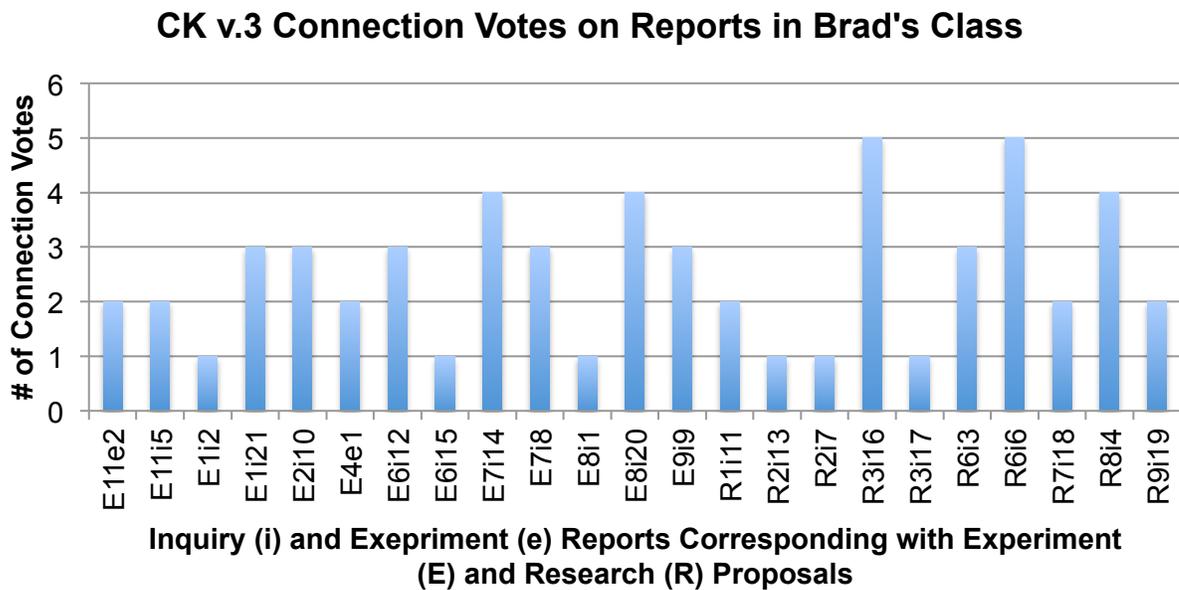


Figure 55. Scatterplot visualizations of the relationship between Proposal popularity (i.e., Promising Inquiry Votes) and Reports, for each class.

Towards the end of phase 3, *Investigate*, students were given the opportunity to go on a “Knowledge Walk” – visiting other interest topic groups, reading their Reports, and speaking with them about their ideas and findings. If a student felt that a Report contributed by a peer from a different interest group connected with their own investigations, the student could tap the Report’s “Knowledge Connection” icon, to indicate their vote. Figure 56 shows the number of Knowledge Connection votes received by each Report contributed by Brad’s class. Reports are identified as being either an Experiment Report (e) or an Inquiry Report (i), and the first two characters in a Report’s identification number indicates its corresponding Proposal. While students in Jen’s class did periodically visit different interest groups, they did not do any Knowledge Connection voting, despite Jen’s choice to extend their inquiry and use of CK for two weeks beyond the timeframe of this study.



*Figure 56.* The number of Knowledge Connection votes each Experiment Report (e) and Inquiry Report (i) received from students indicating “This connects to an idea we’ve worked on”. N = 58 votes in Brad’s class. Jen’s class did not vote on Reports.

In terms of how teachers and students interacted with the public displays, teachers often used the knowledge representation on the Common Board as a grounding reference for guided oral discussions, and often used the “Pause” button to ensure the full attention of students during classroom discussions. On many occasions, teachers employed the tag system to filter the notes in order to address specific content topics during the reflection discussions. As with iterations 1 and 2, teachers also continued to sort notes on the IWB in their iteration 3 enactments, dragging notes into topic clusters, and engaging students in the sorting of new notes into relevant groups. Students were also observed to use the knowledge base on the Common Board as a grounding reference for their small group work, and to occasionally consult the word cloud to view trending ideas.

Similarly, students used the smaller Topic Board displays at their interest group tables as a grounding reference for their interest group work, including the word cloud visualizations. Indeed, students reported in post-enactment interviews that they liked the topic-based segregation of notes on their tablets during the Propose and Investigate phases, and on the distributed public Topic Board displays at topic-focused table groups located around the classroom during the Investigate phase; because it enabled them to isolate the notes that were relevant to their interests and to organize their ideas more efficiently. Furthermore, students liked sitting at topic-based table groups because this enabled them to speak and share with peers who had similar inquiry interests. Finally, teachers and students reported the topic-based colour-coding of Proposals on tablets and the Common Board enabled efficient access to notes that were relevant to their personal interest.

### ***Technology Limitations***

The four tags that emerged from the community's early Brainstorms became structurally vital to the rest of the inquiry script, as second phase Proposals and third phase Reports become organized and spatially located according on these tags. One limitation of this scripted approach is seen in teachers' reports (i.e., in post-session debriefings and post-enactment interviews), that committing to a set of tags was limiting. In particular, the teachers felt that it could take some time for student-driven explorations to progress sufficiently for sophisticated concepts such as "gravity" to emerge. Indeed, in Jen's class, the notion of "Gravity" did not emerge early enough in their explorations to be included as a tag, yet it was an important learning goal articulated by both teachers in the planning stages of this unit. Brad reported in his post-enactment interview that he intentionally guided early classroom discussion during the Brainstorm phase to ensure that gravity would be included as a tag – which it eventually was: within the "Moons, Gravity and Orbits" tag. While knowledge within each of these tags/topics could develop and advance throughout the three inquiry phases, being committed to just four tags early in the inquiry unit limited the evolution and propagation of the community's inquiry topics, which teachers found restricted the community's idea growth beyond the original four topics. Furthermore, third phase Reports were confined within their interest group, which meant that the inter-group knowledge sharing relied heavily on students physically going to the interest group's table to speak with group members and looking at their Topic Board, or at minimum, log in to a different interest group's CK space to read their Reports from their tablets.

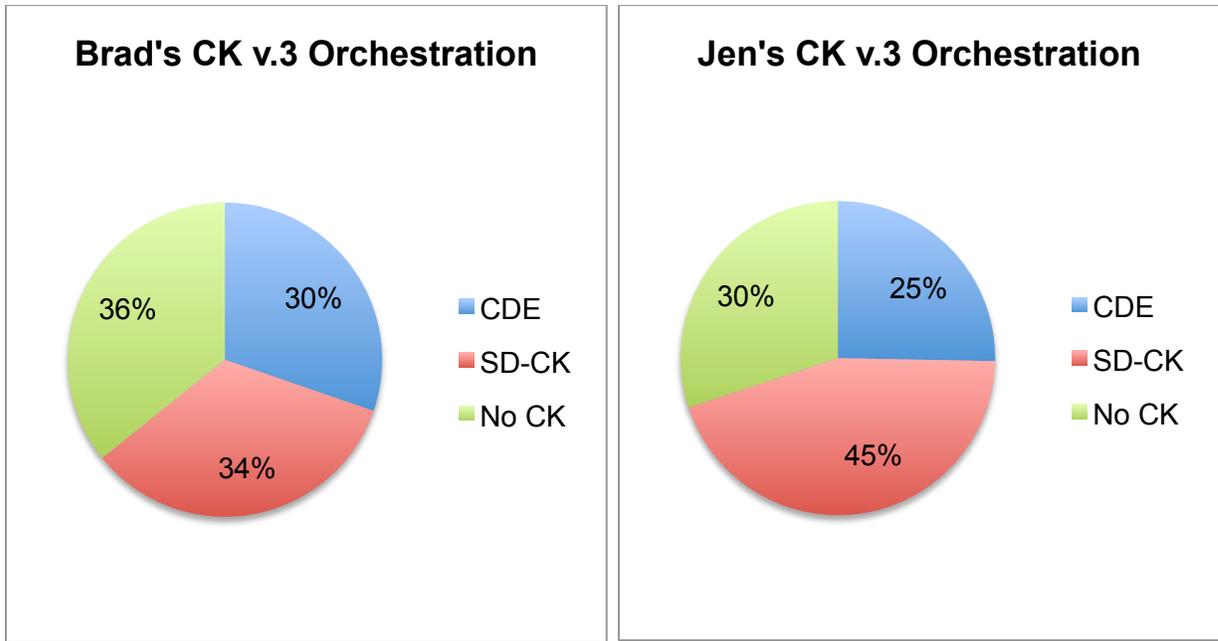
Brainstorm notes were not accessible to students in the *Investigate* (third) phase, as the intention of Proposals was to represent a knowledge progression from brainstorm ideas and questions to specific proposal notes. While the "disappearance" of Brainstorm notes may have cleared away conceptual "noise" so that students could focus on pursuing the inquiry they

themselves had defined, teachers reported they would have liked for students to be able to look back at early Brainstorm notes for purposes of reflecting on the inquiry progress, and also to see if any brainstorm ideas that had been ignored by the proposals could perhaps be connected to the more advanced understandings expressed in Reports. In future iterations, we may choose to give students access to their early ideas (i.e., for purposes of reference or revisiting) but in this third iteration, we made an explicit commitment to removing the “fodder” of Brainstorm notes, as a means of emphasizing inquiry progression.

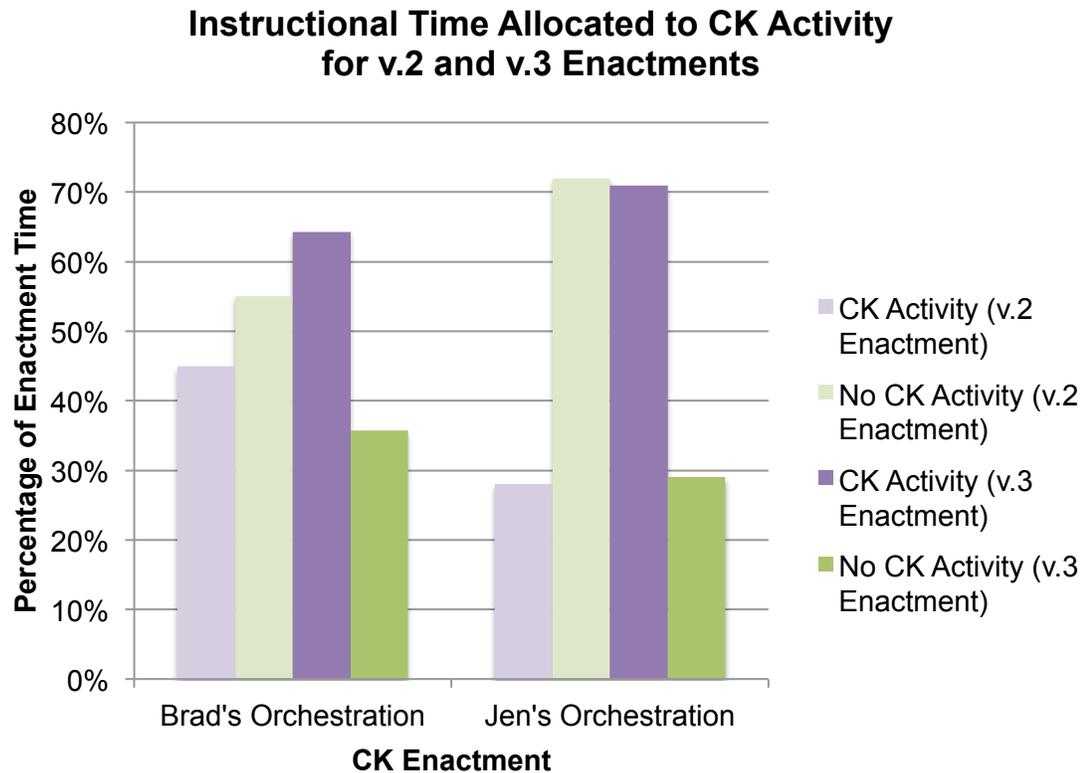
Another technology limitation was that published notes were not re-editable by authors. This was not a problem in the Brainstorm and Propose phases, when each note encompassed a thought that emerged during class time, was therefore fairly short in length, and could be completed within one class session. However, the *Investigate* reports required sustained investigations, sometimes taking several class periods. Hence, students were instructed not to publish their Reports until they were complete. An advantage of this approach was that students maintained focus on their own investigations while they were in progress, and any reports from peers that they did read were in final form. However, there would also be some advantage in allowing students to see peers’ work-in-progress. Perhaps this could promote more knowledge sharing or formative adjustments to reports – for example, if students note that others are also working on ideas related to their own. Other technology limitations included the inability to build-on to Reports, copy and paste text within CK, incorporate media, hyperlink to websites or to other CK notes, and “bookmark” notes for personal information mining/archiving. All of these features have been noted as potential improvements for future iterations.

### **CK Version 3 Enactment: Activity Orchestration**

As in the analyses of previous iterations, I began by coarsely coding the video of all class sessions for teacher-directed (TD) versus student-driven (SD) inquiry activity involving CK, then further coded all TD segments for teacher-guided community discourse episodes (CDE). As shown in Figure 57, teachers spent about two-thirds of the overall instructional time using Common Knowledge. This is a much greater proportion than observed in version 2 enactments, where only half of the overall instructional time was allocated to CK (see Figure 58). Jen showed a dramatic shift in her allocation of instructional time from iteration 2, wherein only 28% of the time was given to activities involving CK; to iteration 3, where 71% was given to CK activities. Several factors may be involved in accounting for why CK was given more prominence in its third iteration during the astronomy unit, than was given to version 2 during the WallCology unit. First, there were many activities associated with WallCology that were explicitly disconnected from CK, requiring other software environments and student activities. Also, teachers (as well as all sixth-grade students, who had been part of the WallCology unit as fifth-graders) were more familiar with CK, which may have allowed greater comfort levels and autonomy. Teacher-guided discourse remained an important instructional strategy, as both teachers were highly experienced with Knowledge Building and inquiry pedagogy, and both continued to use the system to support all community members in the sharing and co-construction of their knowledge, meaningfully and efficiently.



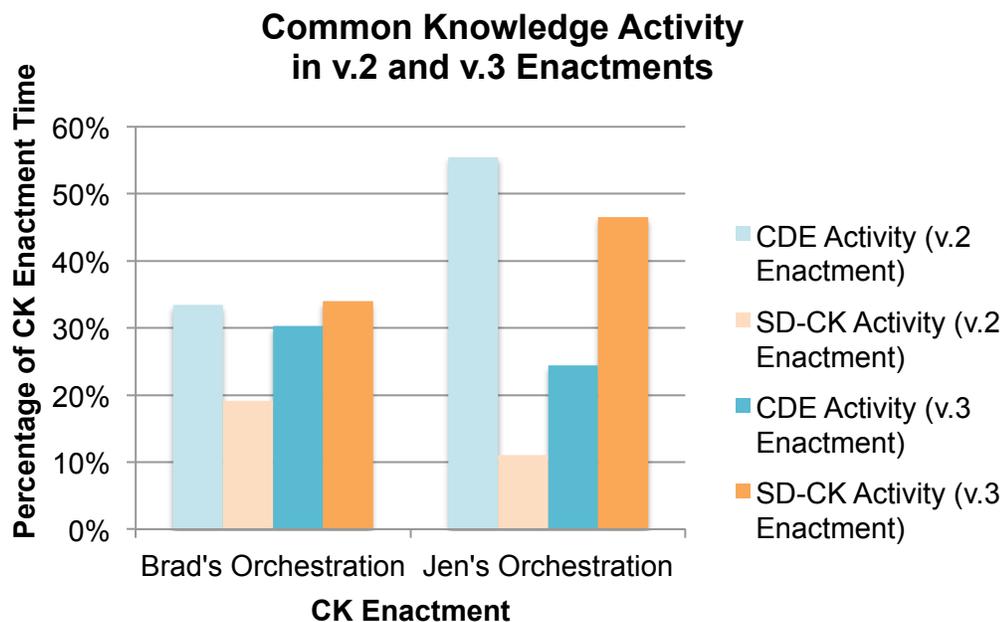
*Figure 57.* Brad's and Jen's proportion of time spent on teacher-guided community discourse episodes involving the use of Common Knowledge (CDE), and time allocated for student-driven inquiry involving the use of Common Knowledge (SD-CK) throughout the 9-week enactment of Astronomy inquiry. "No CK" activities did not involve the use of Common Knowledge.



*Figure 58.* A comparison of teachers' orchestrated time on "CK" activities and activities that did not include CK ("No CK"); throughout CK version 2 enactments, with their CK version 3 enactments. CK is notably higher in version 3 – particularly for Jen.

Figure 59 shows that students in both Brad's and Jen's classrooms spent more time in student-driven than in teacher-guided activities, which is notably reversed from the pattern seen in iteration 2, where teacher-guided activity was favoured (see Figure 59). Again Jen, in particular, showed a dramatic shift in her allocation of classroom time from iteration 2, in which 55% of the time in which CK was a focus was given to teacher-guided community discussion episodes (CDE); to iteration 3, where only 24% was given to CDE. While the increased proportion of total enactment time given to CK (illustrated by Figure 57) may have resulted from changes to the broader instructional unit, this change in allocation of time given to teacher-guided discourse more likely reflects specific circumstances of the CK design. In other words,

the changes made between versions 2 and 3, in addition to any baseline changes in teacher and student experience, made the teachers feel less need to intervene in whole-class discussions, in favour of autonomous student work. Students were now given more time to work independently in the CK environment, enabling them the opportunity to reflect more meaningfully on their own CK contributions and that of their peers. While it is not possible to determine the “best” blend of student-driven versus teacher-directed work, it is interesting to this study that changes to our script and technology features could induce such a large behavioural shift in classroom discourse structures.



*Figure 59.* A comparison of teachers’ orchestrated time on community discourse episodes (CDE) and student-driven inquiry in the CK environment (SD-CK); throughout CK version 2 enactments, with their CK version 3 enactments. SD-CK is notably higher in version 3 – particularly for Jen.

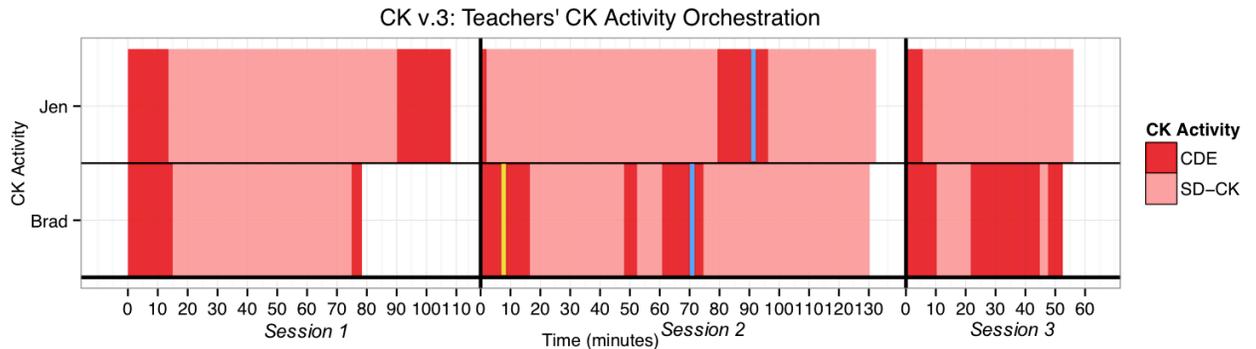
Three classroom sessions – one for each inquiry phase - were chosen for each teacher to be further analyzed, based on the richness of CK-driven discourse and opportunities for CK note

contributions during the same session. Class periods were chosen according to the most uninterrupted usage of CK, in order to capture what might be construed as characteristic inquiry patterns, such as the “3R” orchestration cycle (Reflect-Release-Refocus). In addition, class sessions were preferred that included an inquiry phase transition (i.e., the session in which teachers pressed the “Propose” or “Investigate” buttons). To this end, some sessions were concatenations of the end of one class period and the start of the next day’s class period, which combined to provide rich windows for coding, ranging in length from 60 to 130 minutes.

Although this was a 9-week enactment, students were engaged in various hook activities in the first two weeks, with CK being introduced in the third week. Brad’s and Jen’s first sessions were chosen from the fifth and sixth weeks of the enactment, during the *Brainstorm* phase on inquiry. Their second sessions were chosen from the seventh and eighth weeks of enactment; which for Brad, includes his transition from the *Brainstorm* phase to the *Propose* phase, as well as his transition into the *Investigate* Phase. For Jen, this second session included her transition from the *Propose* phase to the *Investigate* phase. Their third sessions were the final day of the research timeframe, in the ninth week. Interestingly, Jen chose to allow her students to continue with their phase three investigations within the CK environment for two more weeks, and while we have the CK data files for this extended time, we do not have any classroom video recordings or observation notes.

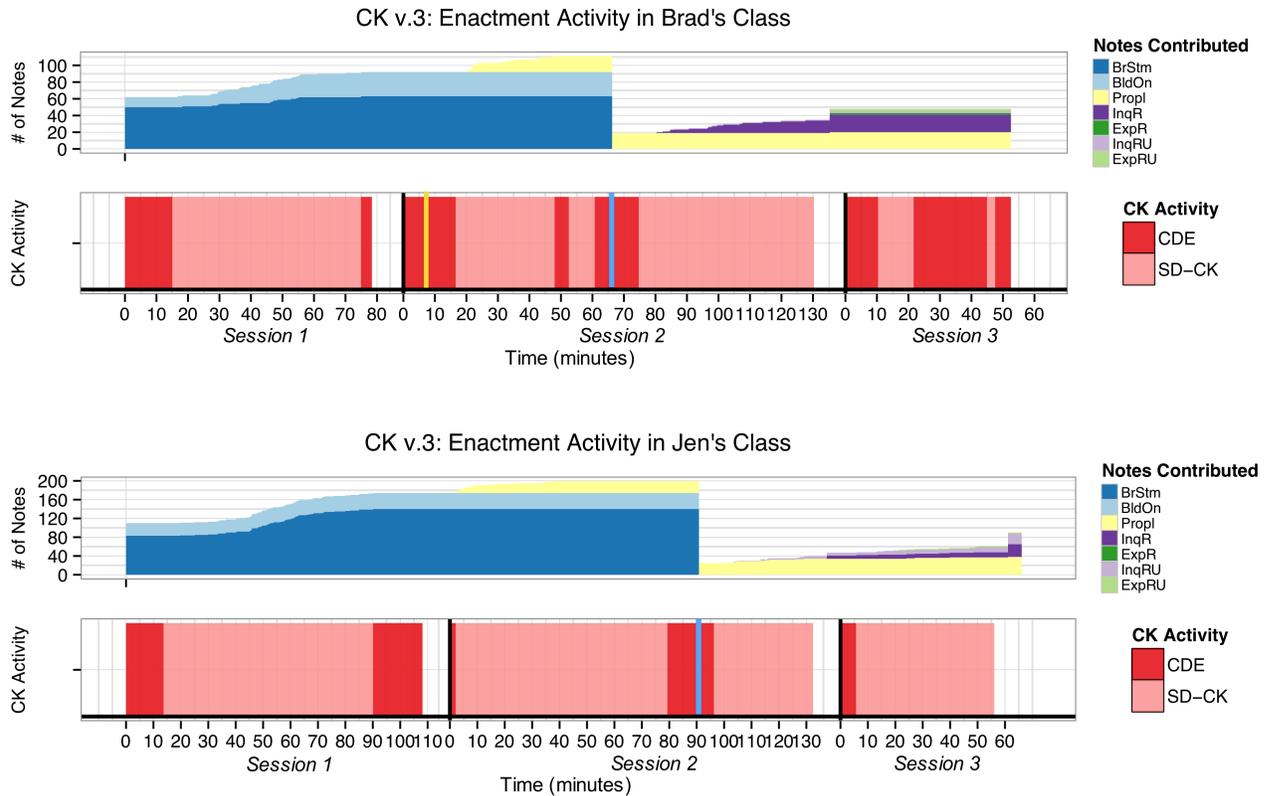
Figure 60 provides a composite timeline of both teachers’ orchestrations of CK activity across the three selected classroom sessions, showing alternating blocks of time between teacher-guided community discourse episodes (CDE) and student-driven inquiry activities (SD-CK). As with iteration 2 enactments, this recalls the “Catch-and-Release” activity pattern, where students are “caught” into community *reflection* discourse episodes, then “released” to work

independently in the CK environment. The analysis of iteration 1 and 2 enactments showed that the Catch phase consisted of two distinct elements: a reflective discussion where the teacher adopted several distinct orientations, and a refocusing instruction, to guide students' subsequent inquiry work.



*Figure 60.* Activity timeline for both teachers' orchestration of CK activity during their three selected class sessions, ranging from 60 to 130 minutes in length. The yellow vertical line marks when Brad initiated the *Propose* (second) phase. The blue vertical lines mark when each teacher initiated the *Investigate* (third) phase. Blank periods on the timeline were occasions when the class engaged in activities that did not involve CK.

Figure 61 provides more details about the teachers' orchestration of CK activity during the three class sessions. The top level of each teacher's panel (i.e., "# of Notes") presents the students' note contribution activity, corresponding to SD-CK events. During the three class sessions, Brad's students contributed 21 Brainstorm notes (including Build-ons), 19 Proposals, and 15 Reports, while Jen's students contributed 64 Brainstorm notes (including Build-ons), 39 Proposals, and 4 Reports. The number of notes shown begins with a non-zero value, as some notes had been contributed in class sessions preceding those that were coded.



*Figure 61.* Enactment timeline for Brad's (top) and Jen's (bottom) orchestration of Common Knowledge activity during their three selected class sessions. The dark vertical lines delineate the end of one class session and the beginning of the next selected session. The yellow vertical line marks when Brad initiated the Propose (second) phase. The blue vertical lines mark when each teacher initiated the Investigate (third) phase. For each teacher, the bottom (red) level shows the orchestration sequencing of teacher-guided community discourse episodes that referenced CK (CDEs) and student-directed work with CK (SD-CK). The top level shows students' contributions of Brainstorms (BrStm, dark blue), Brainstorm Build-ons (BldOn, light blue), Proposals (Propl, yellow), published Inquiry Reports (InqR, dark purple), unpublished Inquiry Reports (InqRU, light purple), published Experiment Reports (ExpR, dark green), and unpublished Experiment Reports (ExpRU, light green).

To orchestrate the transition between inquiry phases, teachers followed students' engagement in a phase until they felt satisfied with how much progress students had achieved (i.e., as revealed by the corpus of CK notes, and whole class discussions), at which point they moved to the next phase. A technology delay created an unduly long Propose phase (2.5 weeks instead of the originally-planned 1 week), which caused some loss of motivation in the two

classrooms, as students and teachers were unable to proceed to their Proposal contributions. Furthermore, students struggled with synthesizing multiple Brainstorms to plan and justify an investigation (i.e., Proposal creation). Teachers suggested in post-enactment interviews that this activity was perhaps developmentally too advanced for their 11-12 year-old students. Student motivation and engagement with the inquiry improved with the deployment of the *Propose* phase in CK, and further improved with the transition into the *Investigate* phase, wherein students were able to pursue their inquiry topics of interest.

### CK Version 3 Enactment: Discourse Patterns

Teachers continued to use CK as a resource to help their students reflect about progress within the knowledge community, about various astronomy phenomena they encountered in their simulation and modeling activities, and about their own theories and those of others. Once again, any CDE that immediately preceded a period of student-driven independent work ended with refocusing instructions, which are summarized in Table 28, and includes the number of student-contributed CK notes referenced by teachers during the CDE discussion. Unsurprisingly (but reassuringly), Figure 61 shows that students' note contributions increased during the SD inquiry periods that follow CDEs, as in the previous iterations.

Table 28  
*Teachers' Paraphrased Refocusing Instructions, Issued During Community Discourse Episodes*

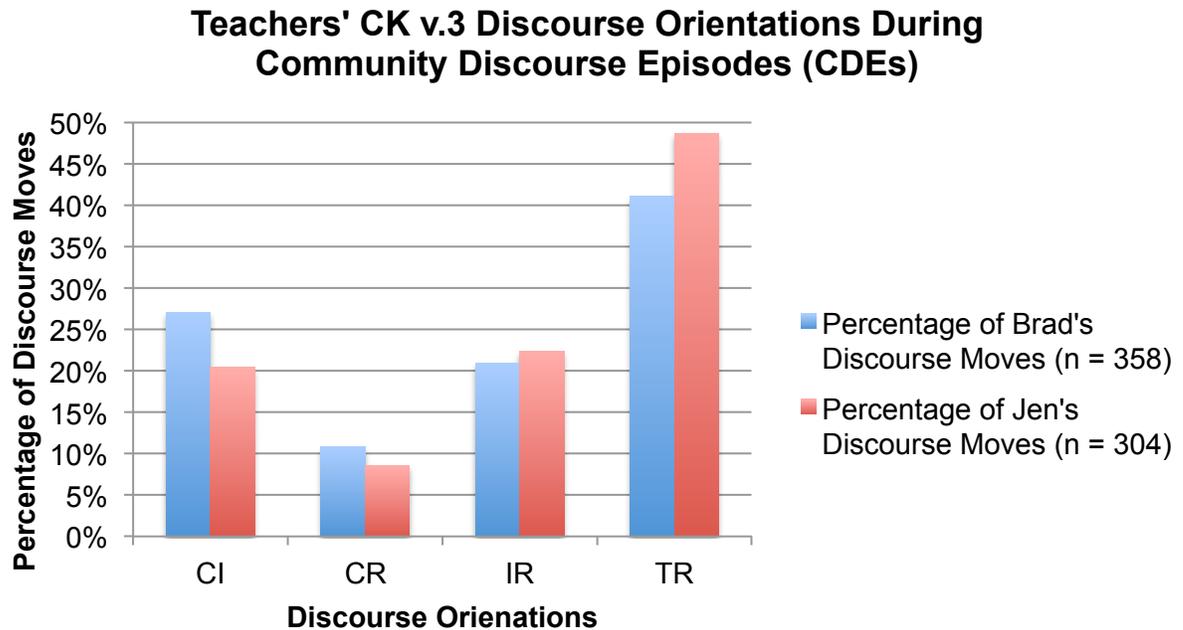
Teacher (CDE#)	# of Notes Referenced	Teachers' Refocusing Instructions
Brad CDE 1	9	Choose a note, read about it, and jot notes in your lab book if it will help you. Then contribute a build-on or new question (in CK) based on what you've written down.
Brad CDE 2	0	Next class, we will read notes that were contributed today.
Brad CDE 3	5	Choose whether you want to work on "Universes", "Planets", "Stars & Nebulas", or "Moons Gravity and Orbits". Choose a couple of notes

		that from that topic. Try to organize them into one project proposal that someone could do.
Brad CDE 4	1	With your partner, read through as many Proposals as you can, and choose 3 Proposals to tap the 'Should we work on this' vote. Think about which Proposals would we learn the most from right away, and should work on first.
Brad CDE 5	4	Choose a Proposal to work on. Jot research notes/observations as an Inquiry note. If you choose to do "research" - can use the books or go online to find information. If you choose to do an "experiment" - can use computer simulations (i.e. found on the class' wiki). If you're not sure where to start, talk to the teacher.
Brad CDE 6	0	Choose a topic/interest group, read for 5-10 minutes, choose 3 Inquiry Reports that you think are connected to something else anywhere...the question is, does it connect to another idea you're working on?
Brad CDE 7	3	Read as many Reports as you can, but don't vote (i.e., Knowledge Connection vote) for more than 3 Reports.
Brad CDE 8	0	Could you walk around and see if you find a word or idea or concept that is big or important on more than one of these word clouds shown on the Topic Screens?
Brad CDE 9	0	Next time, what we'll do is sign-up, and then we can start working on some presentations or other projects.
Jen CDE 1	3	Do some research. Choose an interest group. Read any of the following photocopied articles (corresponding to the 4 tags). Keep the following in mind when "Note-taking from Research Articles": (1) read through twice – first for understanding, and a second time to highlight the big ideas; (2) jot notes about big ideas in your lab book; (3) then use the tablet to contribute CK Questions or Theories.
Jen CDE 2	4	Our ideas are growing in number and in sophistication. We're going to get to the point where we're going to start proposing how we can get to the bottom of our questions.
Jen CDE 3	4	Get into your interest groups and decide which ideas/notes you're interested in, and put them into topic clusters. Then discuss with your group the different ways you can learn about the clusters
Jen CDE 4	0	Choose a Proposal note you're interested in, start a new Inquiry note and begin pursuing the inquiry (as outlined in the Proposal)
Jen CDE 5	3	Continue with inquiry you started last class. Compose Inquiry Notes for research reading. Compose Experiment Notes for simulation explorations.

*Note.* CDE numbers correspond with CDE mappings on enactment timelines (Figure 61).

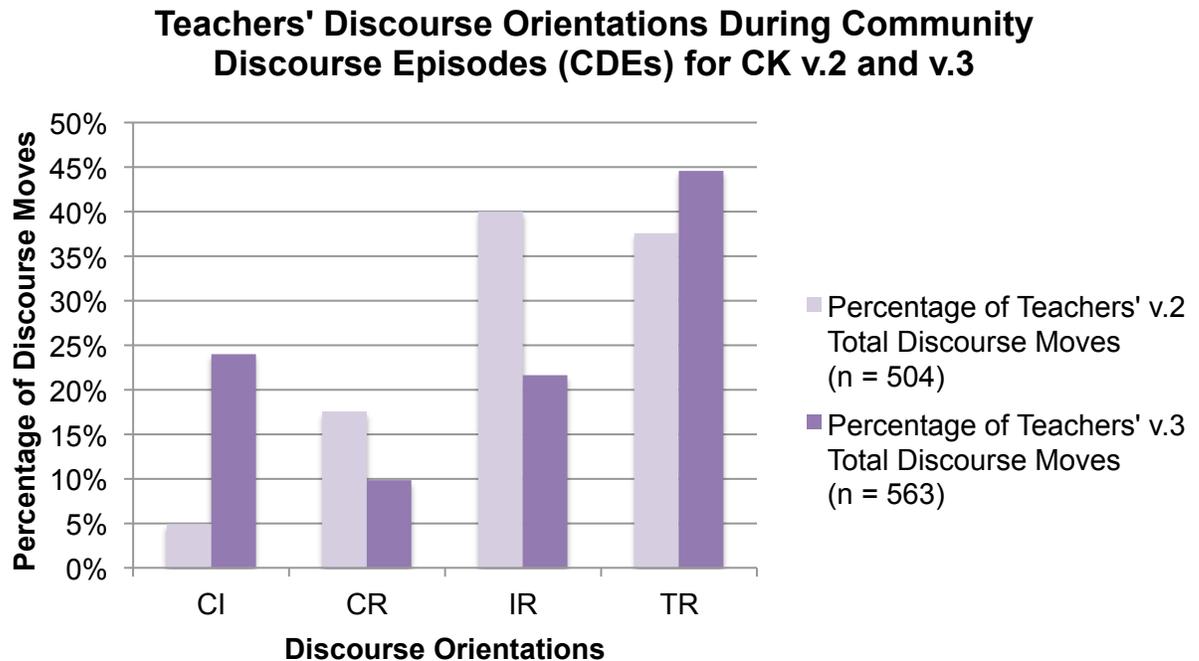
From the first two iterations, four orientations of teacher-initiated exchanges were identified, which occurred primarily in the Reflection discussions: (1) Teacher Reflection (TR), in which the teacher engages in a personal reflection about recent ideas or progress; (2) Individual Student Reflection (IR), in which individual students or groups were posed an inquiry question; (3) Whole Class Reflection (CR), in which the teacher poses a reflection question to the classroom as a whole; and (4) Class Instruction (CI), in which the teacher issued straightforward instructions to the class. From analysis of the iteration 2 enactment, it was found that teachers fluidly used these orientations to guide community discourse, to promote reflection on the community's collective knowledge base, and engage the community in discursive knowledge work.

Figure 62 shows a coding of the discourse orientations from teacher-guided community discourse episodes (CDEs) in iteration three, graphed as a percentage of the total teacher discourse moves over the three selected sessions. This graph shows that both teachers prioritized teacher reflection (TR), with the observed purpose of modeling expert sense-making and inquiry processes for the community – similar to the iteration two enactments.



*Figure 62.* Teachers' discourse orientations during community discourse episodes (CDE), as a percentage of teachers' total discourse moves, over their three respective selected sessions. Teachers' discourse orientations: community instruction (CI), community reflection (CR), individual reflection (IR), and teacher reflection (TR).

Since Brad and Jen had similar discourse orientation patterns to each other, in their second iteration enactments as well as their third; the distribution of teacher orientations in version 3 (collapsing across teachers) were compared with those observed in version 2 (see Figure 63). Notably, teachers placed less emphasis on community reflection (CR) and individual student reflection (IR) in version 3 than they had in version 2, with increased emphasis on community instruction (CI) and teacher reflection (TR).



*Figure 63.* A comparison of teachers' discourse orientations during community discourse episodes (CDE), as a percentage of teachers' total discourse moves, over their selected sessions of v.2 and v.3 enactments. Teachers' discourse orientations: community instruction (CI), community reflection (CR), individual reflection (IR), and teacher reflection (TR).

20% of teachers' video-recorded discourse moves during their selected focus sessions were independently coded for the four discourse orientations (CI, CR, IR, TR) by this study's second rater and me. Inter-rater agreement was 94%, and the inter-rater reliability was found to be Cohen's Kappa = 0.91. Inter-rater disagreements were largely related to occasional difficulty in distinguishing between a teacher's Teacher Reflection (TR) and a Whole-class Instruction (CI) discourse move, stemming from the rater's limited understanding of the classroom community's inquiry context.

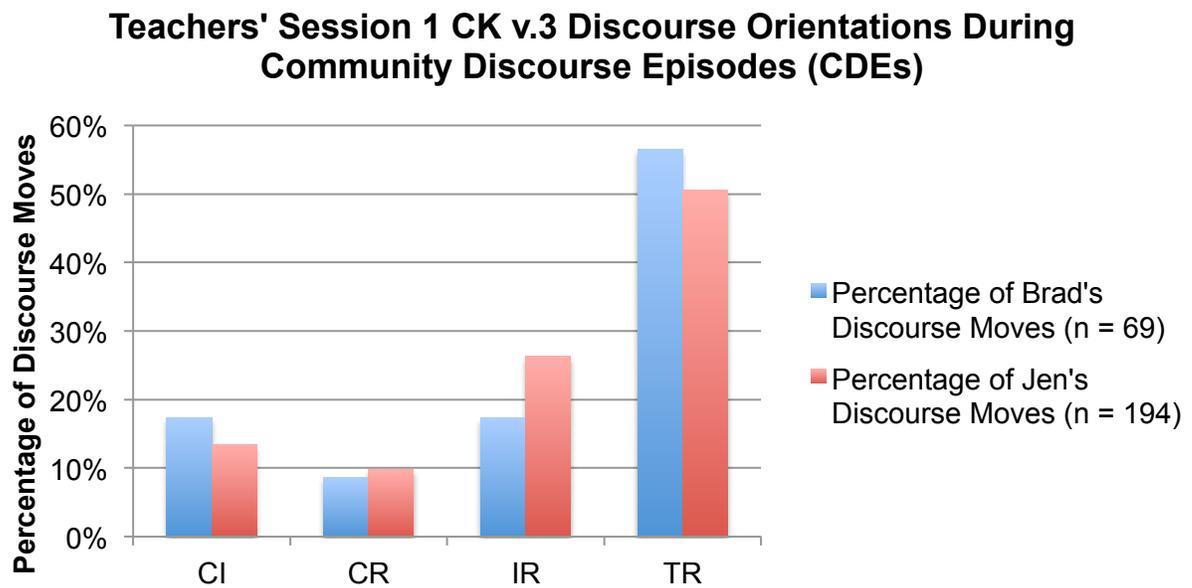
It is interesting to consider whether teachers' discourse patterns shifted in reflection due to the distinct aspects of the three inquiry phases in iteration 3. Perhaps the different task demands and goals for progression would lead to distinct patterns of orientation, reflecting the distinct usage patterns of CK in the different phases. Since the three selected class sessions did not correspond to the exact same points in the CK script for the two teachers, particularly in the case of the second session, we must look at their data separately. Table 29 summarizes the inquiry progression of each teacher's three sessions.

Table 29  
*Inquiry Progression of Teachers' Selected Sessions*

<b>Inquiry Progression of Selected CK v.3 Enactment Sessions</b>		
<b>Session #</b>	<b>Brad's Orchestration</b>	<b>Jen's Orchestration</b>
1	Brainstorm (post bucket-tagging)	Brainstorm (post bucket-tagging)
2	Brainstorm transition to Propose (including Inquiry voting on Proposals), then Propose transition to Investigate	Propose transition to Investigate
3	Investigate (including Knowledge Connection voting on Reports)	Investigate

Since the first sessions are part of the Brainstorm phase, where the goal is to encourage "idea diversity" (Scardamalia, 2002), one might expect that discussions would tend toward questioning, some preliminary theorizing, and – towards the end of the phase when the quantity of Brainstorm notes is much greater - sense-making and idea synthesis. The second sessions are more transitional in nature, requiring some knowledge convergence and idea refinement. The third sessions are focused on student-defined investigations, so the content of teacher-guided discussions might be expected to turn toward knowledge sharing, making peer-to-peer knowledge connections, and sense-making.

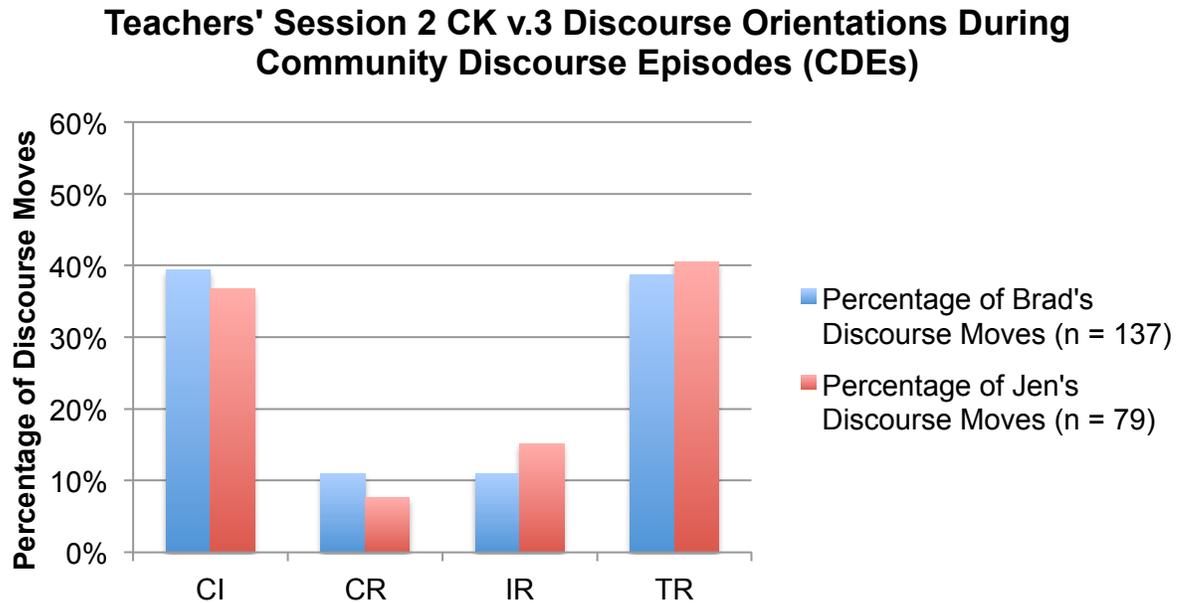
Figures 64-66 show teachers' discourse orientations for each of their selected sessions, revealing that teachers' discourse orientation proportions tend to mirror each other for each selected session, differing systematically from one session to the next. This evidently reflects distinct discourse structures, reminiscent of Polman's (2004) notion of "dialogic activity structures", albeit on a coarser level of granularity.



*Figure 64.* Teachers' discourse orientations during community discourse episodes (CDE), as a percentage of teachers' total discourse moves, during their first selected sessions. Teachers' discourse orientations: community instruction (CI), community reflection (CR), individual reflection (IR), and teacher reflection (TR).

Session 1 (Figure 64) was sampled from the latter part of the Brainstorm phase, in which students were encouraged to contribute their wonderings and ideas freely. Community discussions about Brainstorm notes often involved the teacher reflecting aloud, in essence modeling their sense-making processes as they made connections between the questions and

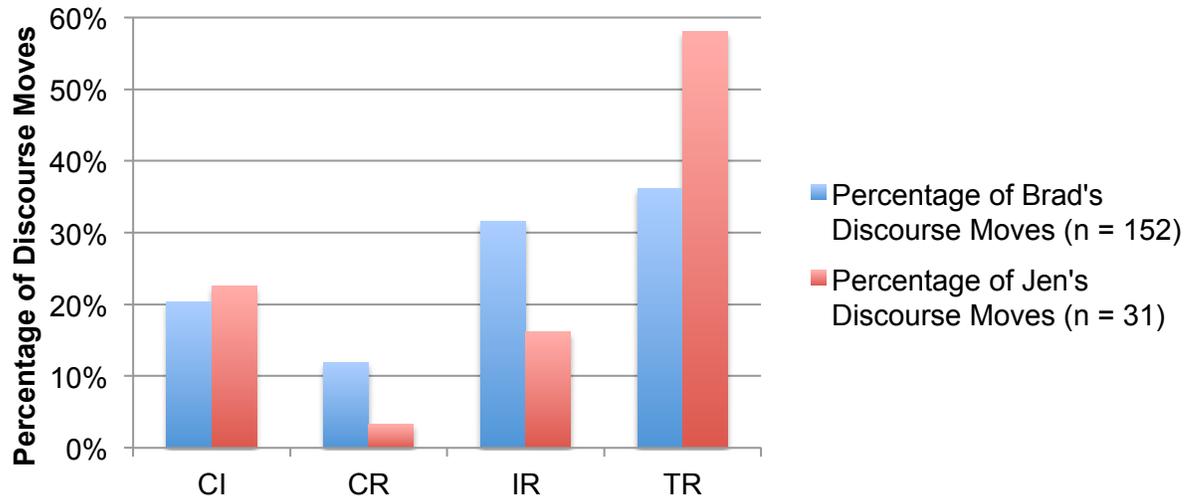
ideas of multiple Brainstorm notes. The teacher's goal during these CDE events was to promote diversity of ideas, encourage students to make connections and illuminate different promising areas for students. So it is not surprising to see in Figure 64 that teachers prioritized their own (TR) and students' (IR) reflection at this early point in the script.



*Figure 65.* Teachers' discourse orientations during community discourse episodes (CDE), as a percentage of teachers' total discourse moves, during their second selected sessions. Teachers' discourse orientations: community instruction (CI), community reflection (CR), individual reflection (IR), and teacher reflection (TR).

Session 2 was sampled from a transitional phase, involving knowledge convergence and synthesis of ideas across multiple notes to form a Proposal, but also requiring considerable technology instruction of the new phase-related features of CK (i.e., new note interfaces, voting tools, etc.). This could account for the observed pattern in Figure 65, where teachers prioritize their own out-loud reflections (TR), as well as whole-class instruction (CI) as they demonstrate new phase-related CK features.

### Teachers' Session 3 CK v.3 Discourse Orientations During Community Discourse Episodes (CDEs)



*Figure 66.* Teachers' discourse orientations during community discourse episodes (CDE), as a percentage of teachers' total discourse moves, during their third selected sessions. Teachers' discourse orientations: community instruction (CI), community reflection (CR), individual reflection (IR), and teacher reflection (TR).

Session 3 was during the final Investigate phase. For Brad, it was a culminating session of a unit; and for Jen, it was sampled mid-way through her *Investigate* phase, which could account for the evident differences between their distributions. It is during this phase that students become knowledgeable about a particular chosen topic of inquiry – specializing in their inquiry focus through sustained experimentation or reference research. The discourse now emphasizes the sharing of one's content understandings, rather than wonderings and theories. Hence, while Figure 66 shows a continued emphasis on teacher reflection (TR), the purposes of these reflections would presumably shift toward a verification of students' contributions, and helping students make conceptual connections to their peers' findings. To confirm or illuminate any such qualitative differences between the content of teacher reflections in iteration 2 and 3, a discourse analysis (i.e., coding) of reflection comments would need to be performed.

Unfortunately, given the time constraints of the research, such analyses will remain for future work that may investigate the finer grain details of discourse within the three phases.

Thus, teachers' three selected session enactments of CK iteration 3 appear to demonstrate the continued use of the 3R orchestration cycle, culminating in pivotal Refocus instructions which guided students' subsequent independent inquiry. There is some indication that teachers' discourse orientations vary with the temporal positioning within the phase inquiry progression of *Brainstorm*, *Propose*, and *Investigate*. As in previous iterations, there are some apparent differences between teachers' discourse orientations across the three phases.

### **CK Version 3 Implications: Design Goals for Future Versions of CK**

Iterations 1 and 2 of CK had been designed for supplementary use, to enable students to author written reflections in their sense-making efforts, including reflections on the collectively gathered data from observations of Embedded Phenomena encountered in HelioRoom (iteration 1) and WallCology (iteration 2). As such, teacher-guided discourse had the sole burden of positioning and advancing student progression through the inquiry script. In contrast, this third iteration of CK was designed as a pedagogical and technological “orchestration technology” (Tchounikine, 2013), scaffolding the communities through a three-phase inquiry progression. In addition to providing new levels of support for the transition between phases, this version directly supported the transport and accessibility of knowledge from one phase to the next, such that each new phase could be seen as continuing the “knowledge work” on the ideas and directions established in the previous one.

Two voting tools – the Promising Inquiry icon (Propose Phase) and the Knowledge Connection icon (Investigate Phase) – served the pedagogical purpose of knowledge

convergence – encouraging students to read each others’ contributions, and to consider whether and how any particular contribution connected with others they had read, while publicly amplifying awareness of notes that had already garnered many votes. Correlational data indicates a marginally significant to no correlation between a Proposal’s popularity and the number of Reports subsequently done by students to pursue the proposed inquiry during the Investigate phase. Furthermore, teachers reported that the voting tools helped them to engage with children and their ideas.

Technologically, this iteration guided workflow within the knowledge communities, organizing the collective knowledge base according to socially negotiated topics and supporting its transformation through the three inquiry phases. The structuring of community knowledge was taken further in the *Investigate* phase, when CK not only organized the knowledge based on topic relatedness, but also distributed the knowledge to different physical locales within the classroom (i.e., the four Topic Boards), making the knowledge base manageable and relevant for students and their varied inquiry interests. Teacher and student interviews, and observational data support the interpretation that physically distributing the knowledge representations and discussions served to support inquiry progress in the *Investigate* phase.

CK supported teacher-guided community discourse episodes by providing visualizations of student ideas and their inter-relations (i.e., through tags, votes and build-ons). In his post-enactment interview, Brad pointed out that children are not expert readers or writers, and that “the most valuable stuff to come out of kids is when it comes out of their mouth”. He described how, either before class or while students were working on CK notes (ie., just before he convened a community discussion) he would review students’ ideas within the CK notes to discern if any student was trying to express a “deep and significant point”, then probe further

about those ideas during oral discussion. Indeed, both teachers were often observed to use this strategy – first to gain a better understanding of what the student meant in their note, but then going further, by using such student clarifications as an entrée into a new concept or new inquiry task. Interestingly, teachers spent less time in such orchestrated discussions in iteration 3, suggesting that they either felt less need to help students progress, or that something about the activity sequencing and technology structures may have inhibited such discussions.

Table 30 presents limitations of iteration 3 technology and activity sequences, mapped to some redesign goals for iteration 4. While there may not be another implementation of a similar unit and instructional script (i.e., allowing for a controlled revision of the existing version according to the recommendations), Table 30 can nevertheless inform any further iterations of CK, to be adapted according to the particular script and technology features.

Table 30  
Summary of CK Iteration 3 Limitations and Redesign Goals for Iteration 4

	<b>Iteration 3 Limitations</b>	<b>Technology Redesign Goals for Iteration 4</b>
<b>Individual Tablet Interface</b>	Proposal creation (i.e., synthesize multiple Brainstorms to plan and justify an investigation) was difficult for students, despite scaffolded text fields.	Combine <i>Brainstorm</i> and <i>Proposal</i> phases, allowing two distinct note types: Brainstorm notes (including Build-ons) and Proposals. Within the Brainstorm note, include a second text field with the prompt: “How could you learn more about this? How could you test your idea?” OR Retain <i>Proposal</i> as a distinct second phase, and give students a means of clustering individual Brainstorms to plan and justify a Proposal.
	Unable to build-on Proposals and Reports.	Enable build-ons for Proposals and Reports
	Brainstorm notes were inaccessible during <i>Investigate</i> phase.	As in the <i>Propose</i> phase, allow read-only access to Brainstorms during <i>Investigate</i> phase.
	No inter-group note-sharing during	Enable inter-group note-sharing during

	Investigate (third) phase.	the <i>Investigate</i> phase.
	Unable to copy text from within CK, and paste it into a new note.	Enable copy-paste of text from within CK, and pasting of URLs into CK notes.
	Unable to quote fragments of text from a published CK note within a new CK note, with reference to the originating note.	Enable quoting of text fragments from a published CK note into a new CK note, with (hyperlinked) reference to the originating note.
	Unable to incorporate media (i.e., image, sound, or video files) into notes.	Enable incorporation of media (i.e., image, sound, or video files) into CK notes.
	Published notes were not re-editable.	Enable author re-editing of their published notes.
	From within a note, unable to hyperlink to a website or to another CK note.	Enable hyperlinking to a website or to another CK note.
	No repository for students to collect/bookmark CK notes for personal information mining/archiving.	Give each student his or her own repository (i.e. “cubby”, or “backpack”) in which to collect/bookmark CK notes for personal information mining/archiving.
<b>Public Interface (Common Board &amp; Topic Boards)</b>	Tags could not evolve/propagate to keep up with community’s idea development.	Allow teacher to edit existing tags and to add more tags.
	Brainstorm notes were inaccessible during <i>Investigate</i> (third) phase.	As in the <i>Propose</i> phase, allow read-only access to Brainstorm notes during <i>Investigate</i> phase.

## Chapter 6: Discussion and Conclusions

The design and evaluation of Common Knowledge was organized around notions of a Technology-Activity-Discourse system, as a way of understanding the interactions between the specific CK technology features, inquiry script designs, teacher orchestration patterns and discourse that occurred within the classroom. Recognizing that the enacted form of an intervention could depart from its designed (i.e., intended or envisioned) form, it was also important that the analysis distinguish between what was designed or intended (i.e., the design analysis) and what actually transpired in the classroom (the enactment analysis). Indeed, some aspects of the design were left intentionally underspecified, as we did not want to overly script the patterns of activity in any iteration. Teachers and students were given autonomy within each iteration, allowing for student-driven content, and supporting the emergence of teacher orchestration patterns and discourse patterns. This chapter begins by revisiting the key findings and developments of this research in the dimensions of (1) technology features, (2) activity sequences, and (3) teacher-guided discourse.

### **Technology Features**

Although the first two iterations of Common Knowledge were employed in close connection with other inquiry tools and environments (i.e., HelioRoom and WallCology inquiry tools), CK itself is largely content-agnostic. That is, the student brainstorm notes, tags, proposals or inquiry notes could be written about any science topic or domain. The overarching goal, consistent with KCI principles, is to support students as they add to and edit a knowledge base, then make use of that knowledge base for purposes of inquiry. To that end, the technology components of CK served two main dynamics: (1) facilitating idea diversity and knowledge

convergence to scaffold student reflections and inquiry, and (2) supporting teachers as they orchestrated the progression of inquiry.

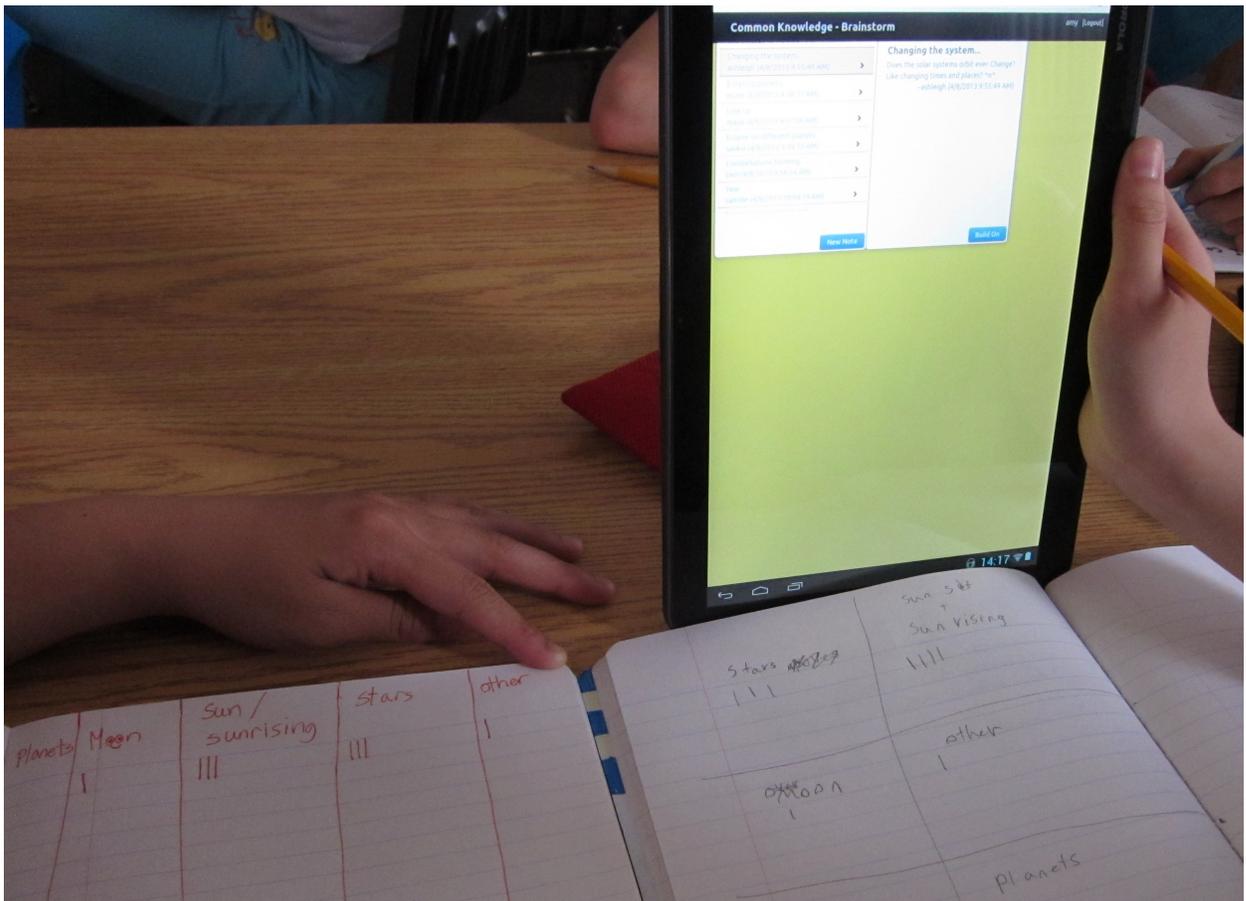
### **Supporting Idea Diversity and Knowledge Convergence**

One important feature of knowledge building technology environments is that they promote “idea diversity” (Scardamalia, 2002). This is achieved by virtue of the externalization of student ideas in the form of persistent notes, such that they are available to peers and teachers for purposes of motivating or inspiring new ideas, building on existing ones, or synthesizing across multiple ideas to create higher level concepts or organizational schemes. In CK, students were encouraged to share questions and ideas that emerged from their explorations of various inquiry activities (in the HelioRoom, Wallcology, and Astronomy units). The technology itself supported this process through two distinct form factors: the student tablet and the class Common Board. Both devices represented ideas in such a way that their aggregate collection was viewable and sortable. Iterations 2 and 3 also included tags that allowed the Common Board to be filtered, such that subsets of related notes could be examined and discussed (Figure 67).

The two distinct forms of display introduced a productive opportunity for students, who could use the public displays to gain a more global awareness of their community’s overall state of knowledge, including the relationship to the tags and topic clusters. While students could read and compose notes from their tablets, such knowledge relatedness was not readily apparent on the tablet interface, which simply listed a note’s associated tags at the end of the note, and tag-based colour-coding of Proposals. The tablets were used by students to capture their ideas, and to read their peers’ notes. It was through the public displays that they gained a sense of knowledge relatedness and inquiry progress. Furthermore, spatially distributing the Topic Boards in the classroom helped to form small interest-based groups and focused students’



keywords (Figures 67 and 68). Any new Brainstorm notes could then support this higher order structure by adding to the tagged collection. However, Brainstorm notes that were deemed not to fit with any of the socially-negotiated tags (i.e., during bucket-tagging) fell by the wayside. This “productive constraint” (Slotta, 2013) served to limit the community knowledge base to notes relating to the socially-negotiated topic categories (i.e., tags). Finally, students were asked to interpret the content of the brainstorm, resulting in higher order Proposal notes. Jen’s class contributed 140 brainstorm notes, only 10 of which did not end up with any associated tags, while Brad’s class contributed 63 Brainstorms, all but one of which were tagged.



*Figure 68.* Jen’s class decided to create topic tallies of Brainstorm notes, as a systematic way to identify the emergent topics. Here, a student dyad reads through their community’s Brainstorms from their tablet, and tallies topics they feel have emerged from the community’s Brainstorms.

Subsequent to the *Propose* phase of iteration 3, where CK supported knowledge convergence, a new cycle of idea diversity could begin as students added their *Investigate* notes to the knowledge base. At this point in the script, all Brainstorm notes were no longer accessible – another intentional productive constraint, serving to focus the knowledge community’s attention on carrying out their proposed investigations. Brad’s class generated 23 published Reports and 5 unpublished Reports from their 20 Proposals, while Jen’s class generated 27 published Reports and 25 unpublished Reports from their 38 Proposals. Proposals for both classes were analyzed for their Proposal-to-Report knowledge congruity, with the finding that Reports generally made some explicit reference to a corresponding Proposal note.

Two additional tools helped to guide the diversification and convergence of knowledge. The Promising Inquiry (on Proposals) and Knowledge Connection (on Reports) voting tools allowed students to weigh in on the importance of various Proposals and Reports, and publicly displaying aggregate vote results served to elevate the relevance of notes with more votes. In both classes, such votes spurred community discussion about why students found the Proposal or Report to be important. The “Promising Inquiry” voting tool, which appears as a light bulb icon on published Proposals, enabled students to indicate how worthwhile they thought a Proposal was to the community’s collective knowledge advancement. Thoughtful voting necessitated that students read through all the Proposals, thereby increasing their awareness of the overall state of the community’s knowledge. The public display of aggregate votes for each Proposal served to highlight promising Proposals, offering the community an opportunity to see which Proposals generated the most interest. Indeed, both teachers were observed to use these votes to spur community discussion about why students thought certain Proposals were so worthwhile. However, a marginal (Brad’s class) to no significant correlation (Jen’s class) was observed

between a Proposal's popularity and the number of Reports subsequently done by students to pursue the proposed inquiry during the Investigate phase.

Another opportunity for knowledge convergence was provided by the "Knowledge Connection" voting tool, which appeared as a double-headed arrow on published Reports during the *Investigate* phase. As with the "Promising Inquiry" voting tool, thoughtful knowledge connection voting necessitated that students read through all Reports, reflecting on whether they offered any conceptual connections to their own investigations, thereby increasing students' awareness of their community's state of knowledge. Public display of aggregate votes for each Report highlighted the Reports that were seen by students as being well-connected, offering teachers another means of engaging with students about the content within their knowledge base. Indeed, Brad was observed to use these aggregate votes as a discussion prompt, asking students who voted on popular Reports to explain why they voted for it and how it connected to something else they learned in their investigations.

Dynamic word clouds accessible from all public displays during the Brainstorm and Investigate phases provided another means of formative assessment of the ideas within the community and topic groups. On some occasions, students were observed to approach a public display to view the word cloud during a work period. In one community discussion, Jen showed her class a word cloud from a few sessions earlier, then showed her class the current word cloud, to give them a sense of how many more ideas they had since worked with. Brad instructed students to visit the Topic Boards of each interest group to look at their word cloud, then think about which ideas looked prominent on more than one interest group's word cloud. Thus the word cloud was used to spur reflection about conceptual progress and conceptual convergence.

## Scaffolding Orchestration

The enactment of any pedagogical design – particularly if technology environments are involved – requires management of students, activities, resources, technology, and time. This has been defined as the notion of orchestration: “how a teacher manages, in real time, multi-layered activities in a multi-constraints context” (Dillenbourg et al., 2012). The inquiry and collaborative scripts at the heart of CK’s design, together with the various visualizations, offered a means for the community to process the complex array of incoming ideas arising from all members essentially “talking” simultaneously. The CK technology environment supported teachers in orchestrating the community’s progress through the inquiry script, offering teachers knowledge visualizations of the community knowledge base; with which to guide whole class discussions, and inform decisions about appropriate orchestrational moves. Dillenbourg (2013) offers a set of design principles for orchestration tools, which can be used to summarize the orchestrational aspects of CK technology (see Table 31).

Table 31  
*Summary of CK’s Orchestrational Design Features*

<b>Orchestration Design Principles</b>  <b>(Dillenbourg et al., 2013)</b>	<b>CK v.3 Technology Features</b>
<b>Control:</b> teacher is in control.	<ul style="list-style-type: none"> <li>• Teachers controlled when the community progressed to a new inquiry phase and initiated the technology’s change of state</li> <li>• Teachers could instantaneously gain student attention by locking all tablets, using the “Pause” button</li> </ul>
<b>Visibility:</b> make the invisible visible.	<ul style="list-style-type: none"> <li>• IWB Common Board and interest group Topic Boards displayed real-time idea and activity flow of the community and small groups, visualized as: (1) tag/topic-based webs, (2) word clouds</li> <li>• Aggregate vote results from the “Promising Inquiry” voting tool on Proposals and the “Inquiry Connection” voting tool on Reports were publicly displayed, raising community awareness of their worthwhile Proposals and conceptually-connected</li> </ul>

	<p>Reports</p> <ul style="list-style-type: none"> <li>Community's progression from one inquiry phase to the next, with the name of each inquiry phase prominently displayed in the centre of the IWB Common Board, gave a sense of inquiry progress</li> </ul>
<p><b>Flexibility:</b> possibilities for on-the-fly adaptations, to address learners' needs and to react to extrinsic events/constraints.</p>	<ul style="list-style-type: none"> <li>Teachers had full freedom to adapt the curriculum and orchestration script to fit their real-time contexts</li> <li>Teachers had <i>limited ability</i> to adapt the technology script; they could choose when to proceed in the technology script, but they <i>could not revert to a previous state in the technology script</i></li> <li>The 4 tags were determined by the community in the latter part of the Brainstorm (first) phase; <i>existing tags could not be changed/deleted and additional tags could not be added thereafter – this somewhat constrained the community's breadth of inquiry</i></li> <li>Students drove their own questions and investigations</li> <li>Students could rejoin different interest groups as their inquiry trajectories developed</li> </ul>
<p><b>Physicality:</b> spatial organization of information affects classroom social processes; consider mobility, gaze, and distance between actors.</p>	<ul style="list-style-type: none"> <li>Tablet display afforded individual inquiry activities</li> <li>Distributed interest groups among separate tables and dedicated Topic Boards (shared displays) allowed students to focus on their topic of interest, as well as collaborate and socially interact with peers of similar interests</li> <li>IWB display connected the community's collective ideas and visualized the community's idea and activity flow, serving as a common referent for community oral discourse – from anywhere in the classroom</li> </ul>
<p><b>Minimalism:</b> “less is (sometimes) more”; consider teachers' cognitive load and minimize teachers' orchestration load.</p>	<ul style="list-style-type: none"> <li>A contributing factor to orchestration load is the real-time monitoring of incoming notes and the tracking of a community's idea trajectories</li> <li>Ability of note icons to be moved on public displays enabled simple clustering of related notes</li> <li>Visual connections between notes and corresponding tags, or between Proposals and corresponding Reports organized the community's ideas and activities, enabling at-a-glance formative assessment</li> <li>Tag nodes on public shared displays also functioned as note filters, minimizing visual clutter</li> <li>The technology scripted phases of inquiry process, thereby relieving the teacher of having to transition the students from one phase to the next – <i>yet the teacher's role was critical in preparing students for phase transitions</i></li> </ul>

## Activity Sequences for Collective Inquiry

The first two iterations of CK were designed as a supplementary note-sharing tool to complement content-embedded scripted inquiry activities focused on HelioRoom and WallCology Embedded Phenomena. The third iteration of CK was a content-agnostic technological and pedagogical intervention designed around a KCI script for grade 5/6 astronomy, serving to guide knowledge communities through distinct phases of inquiry, and to scaffold their knowledge work within and between these phases. The activity script served to describe the organizational structure (e.g., student grouping), role of visualizations (aggregate displays, notes and votes), activities. These activity sequences, present to a lesser degree in the early iterations, supported knowledge community and inquiry in three aspects: (1) managing workflow, (2) promoting awareness of process and knowledge product, and (3) making knowledge accessible. Taken together, these dynamics served to support the four KCI principles (Slotta, 2013):

- Principle 1. Students work collectively as a knowledge community, creating a knowledge base that serves as a resource for their ongoing inquiry within a specific science domain.
- Principle 2. The knowledge base is accessible for use as a resource as well as for editing and improvement by all members.
- Principle 3. Collaborative Inquiry activities are designed to address the targeted science learning goals, including assessable outcomes.
- Principle 4. The teacher's role must be clearly specified within the inquiry script, but also include a general orchestration role.

## Managing Inquiry Workflow

The combined technology and inquiry activity scripts were designed to move knowledge communities through distinct phases of inquiry, with CK serving to help manage transitions through structural progressions, or through the use of discourse events that advanced the nature of student inquiry. In iteration 2, we saw the nature of teacher communications change over time, which was found to be congruous with the resulting student notes. In iteration 3, CK technology actually distributed student notes for further processing as part of the inquiry workflow. In iteration 3, the Common Board included a set of buttons in the bottom-right corner (one for each phase; see Figure 69) that served to visually represent the three inquiry phases, as well as to allow the teacher an explicit means of advancing to the next stage.

Each inquiry phase had a corresponding technology state that determined what note types would be accessible to students and how these published note types would be visualized for public display. There was also a “Tagging” button, which teachers used towards the end of the Brainstorm phase to initiate bucket-tagging. The other two buttons, “Propose” and “Investigate”, enabled the teacher to initiate those phases. The visualizations provided during each of these phases served to reinforce the state of the inquiry, and allow the teacher access to student ideas for purposes of whole class discourse (see Figures 69 and 70).

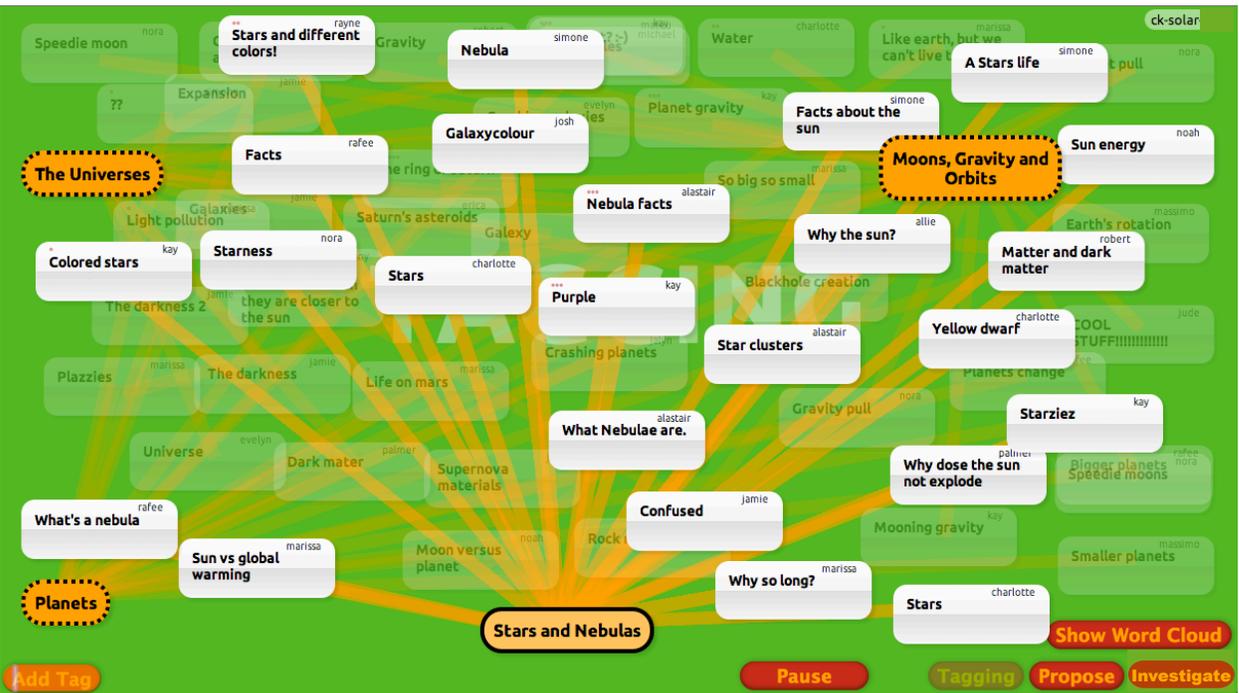
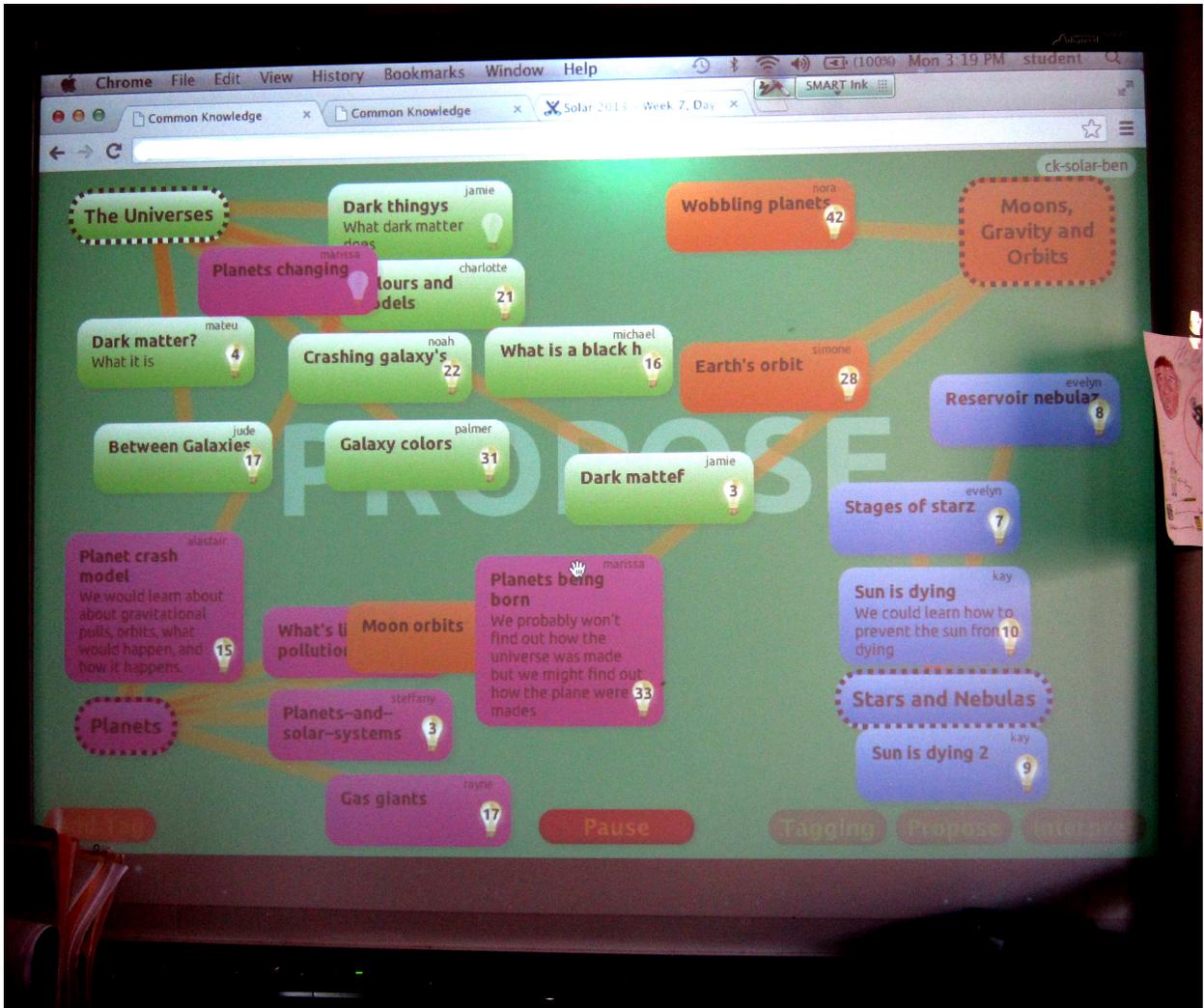


Figure 69. Top: Common Board display for Jen’s class during the Brainstorm (first) phase of inquiry, before bucket-tagging. Bottom: Common Board display for Brad’s class during the Brainstorm (first) phase of inquiry, after bucket-tagging. Three buttons in the bottom-right corner enable teachers to initiate a new phase of inquiry and its corresponding technology state: “Tagging”, “Propose”, “Investigate”.

Phase transitions were initiated by teachers during class discussion, with the students watching. Such transitions occurred when teachers deemed their students ready, based on the level of student motivation and on the state of the community's collective knowledge base. Each phase transition resulted in a distinct public display. For example, notes appeared as individual white icons with no connections to anything early in the Brainstorm phase (see Figure 70, top), but upon the teacher's press of the "Tagging" button later in the Brainstorm phase, bucket-tagging began, and as students tagged the randomly distributed Brainstorms from their tablets, the Common Board displayed each tagged Brainstorm note icon connected to their associated tag node(s) with an orange line(s) (see Figure 69, bottom).

When the teachers pressed the "Propose" button, all of the Brainstorm notes disappeared, leaving only the (now colour-coded) tag nodes, and Proposal note icons (also colour-coded by tag) visible on the Common Board, connected by an orange line to their associated tag node, as they become published by students (see Figure 70). The CK knowledge base, which had shown the Brainstorm notes during the previous phase, was now divided into four separate knowledge spaces – one space for each tag. Tags were elevated to the status of "topics", and all tagged Brainstorm notes were now redistributed to appear only in their topic's knowledge space, which would now begin to represent Proposals and Reports associated with that topic.



**Common Knowledge - Specializing in Moons, Gravity and Orbits** allie [Logout]

<p>Proposal - Blackholes model mateu (5/6/2013 3:08:09 PM) &gt;</p>	<p><b>Moon orbits</b></p> <p><b>Proposal:</b> Someone asked if each moon had its own gravitational pull... So again maybe we could look on solarium an see how the moons are moving we the planet or around something else in the solar system I. E. The sun. We could also do some more research about the moons. And maybe depending on the position of the planets the moons might revolve around different things. <b>Justification:</b> I think that we would learn hopefully learn the answer to</p> <p>Should we work on this? </p>	<p><b>Propose and Justify</b></p> <p>Headline (3 word max)... <input type="text"/> <input type="button" value="Research"/> <input type="button" value="Experiment"/> <input type="button" value="Share"/></p> <p>What should we do? How should we do it?</p> <hr/> <p>What might we learn?</p>
<p>Proposal - Moon orbits nora (5/6/2013 3:09:36 PM) &gt;</p>		
<p>Proposal - Planets changing marissa (5/6/2013 3:13:01 PM) &gt;</p>		
<p>Proposal - Between Galaxies jude (5/6/2013 2:47:53 PM) &gt;</p>		
<p>Proposal - Colours and models charlotte (5/6/2013 2:47:15 PM) &gt;</p>		
<p>Proposal - Earth's orbit simone (5/6/2013 2:47:59 PM) &gt;</p>		
<p>Proposal - Wobbling planets</p>		
<p><input type="button" value="New Proposal"/></p>		

*Figure 70. Top:* Common Board display for Brad’s class during the Propose (second) phase of inquiry. Tag nodes (which act as filters) and Proposal icons are colour-coded by tag. During the Propose phase, Brainstorms are no longer visible from the Common Board, but can still be accessed by students from their tablets. *Bottom:* tablet interface during the Propose phase. Proposal notes associated with different tags appear in the note index (left panel), colour-coded by tag (as they are on the Common Board), and Brainstorms appear in the note index as white (as they did during the Brainstorm phase).

Upon the teacher’s press of the “Investigate” button, there was no change in the note visualization on the Common Board (see Figure 71, top), but all four of the Topic Boards at each interest group’s table become activated (see Figure 71, bottom). Each of these Topic Boards were given their own distinct colour, contrasting with their topic-based colour-coded Proposal notes that appear on the Topic Board. The four interest topics have now been physically redistributed to different locations in the classroom, requiring students to relocate themselves according to their topic of interest, resulting in groups of students who have common inquiry interests sitting together at interest-based tables. Such interest-based co-location enables students with common inquiry interests to dialogue about their work and offers opportunities for collaboration on investigations.

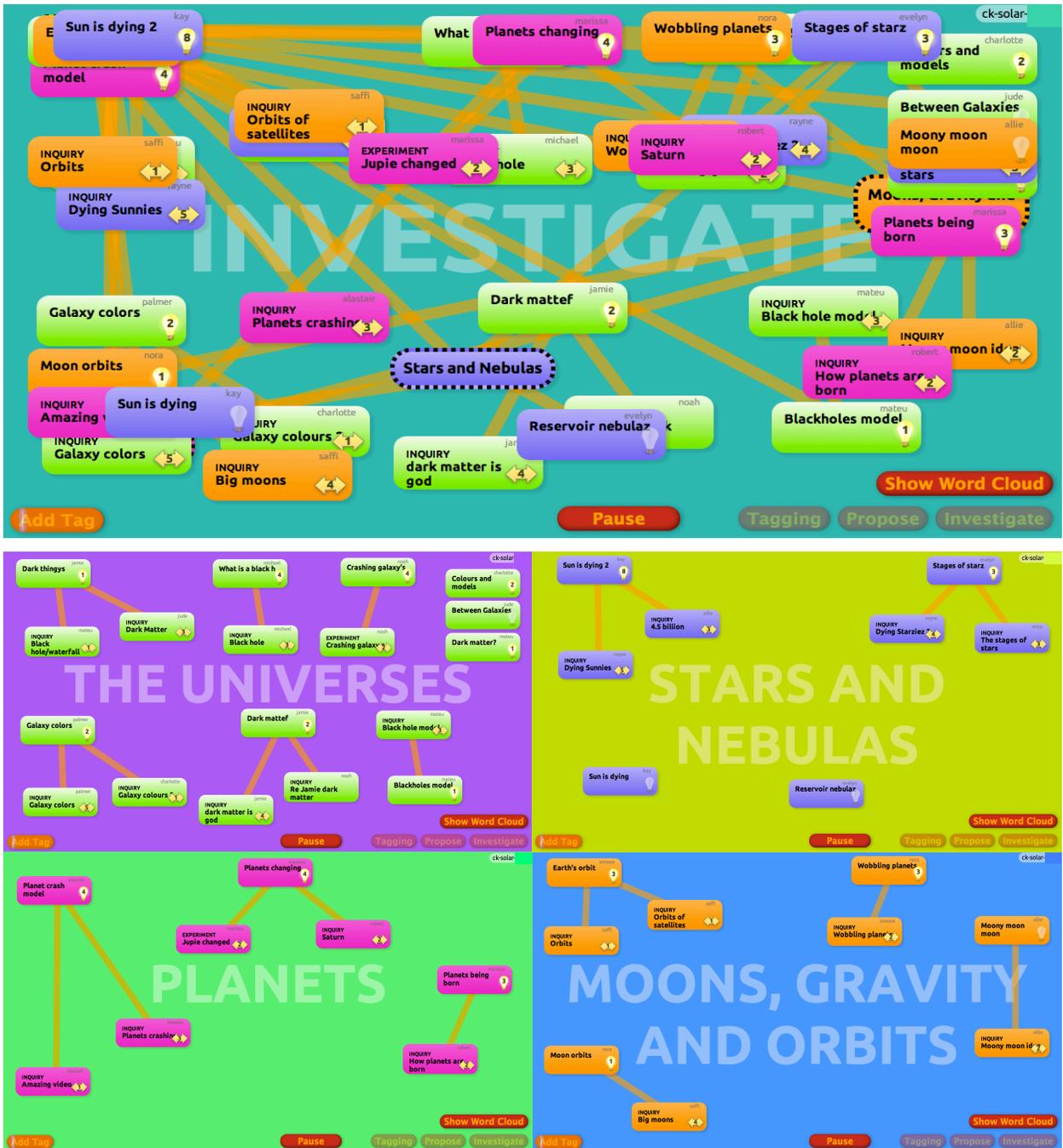


Figure 71. Top: Common Board (displayed on the classroom’s IWB) for Brad’s class during the Investigate phase. Tag nodes (which act as filters) and Proposal icons remain colour-coded by tag. These colours remain consistent through all Topic Boards. Bottom: Topic Board displays for all four interest groups in Brad’s class.

Thus, CK served to help students and teachers alike in managing or orchestrating the progression through the sequence of activities, such that the goals of inquiry were firmly at the

foreground and all participants felt a sense of progress. The next section provides more detail of how CK helped to promote and maintain awareness of the inquiry progression.

### **Promoting Awareness of Process and Knowledge Product**

Vital to the community's progress through the CK inquiry script was an awareness of the community knowledge base in terms of its contents as well as its progress over time. Teachers could point to gaps, weaknesses or disagreements in such a way that students would respond in their next round of note sharing. It was also essential for all community members to maintain an awareness about the current processes or requirements that were at play. CK provided teachers and students with persistent cues about their current inquiry phase, allowing the teacher to maintain an awareness about the task at hand. For each inquiry phase, the Common Board prominently displayed the name of the current inquiry phase in large lettering at its centre (see Figures 69-71). Students' tablet interfaces also displayed the name of the current inquiry phase at the top of the screen.

Awareness about the level of progress in the inquiry was achieved through scripting knowledge convergence – such as the social negotiation of tags – as well as through technology elements like the voting tools. The process of socially negotiating tags part way through the *Brainstorm* phase obliged students to first read through their community's Brainstorm notes to extract common themes. In doing so, they gained awareness of the community's progress in populating the knowledge base (i.e., the products of their inquiry) as well as the level of achievement (i.e., the progress within the stage. The “Promising Inquiry” voting icon on Proposals, coupled with the teachers' instruction that each student may cast a total of three votes, again obliged students to read through all Proposals, and develop an awareness of the knowledge base. The “Knowledge Connection” icon on Reports again compelled students to read their

peers' Reports, and thereby develop awareness of how the Report notes connected with other Reports they had read.

Awareness was also promoted through the use of tags as organizational structures for the community's knowledge. After bucket-tagging in the Brainstorm phase, visual connections on the Common Board between note icons and tag nodes enabled students and teachers to maintain awareness of what tags were being explored, which ones they were interested in, and what kinds of notes had been added to those tag categories. The simple act of tagging their own note required students to reflect about how the tag(s) connected with the ideas they had written about, with other notes that shared that tag. Having students "declare" their topic of interest in the *Investigate* phase served to raise their awareness of specific progress in that category. This was emphasized visually on students' tablet interface, which showed the student's chosen topic. Finally, CK helped to maintain student awareness about progress within their topic and those of other groups through visual representations presented on the topic boards and the IWB Common Board (see Figure 70, bottom).

Published Proposals provided conceptual beacons that represented community progress and interests, serving to guide student ideas for inquiry (see Figures 71 and 72). Research and Experiment Report notes scaffolded awareness about the inquiry processes by including specific fields with textual prompts that helped make the constituent elements of the inquiry more accessible (see Figure 72, middle and bottom).

**Common Knowledge - Investigating orbits and seasons**

Proposal - How we can answer this question oliver (5/13/2013 9:51:14 AM) >	<b>Moon closer earth</b> <b>Proposal:</b> Note about the note too close by Ashley not ashleigh Resources to use stimulation talking to experts and go on Google / research articles What I would look up what would happen if the moon came too close to earth This would be helpful because it is exactly what the question is asking I could also use a stimulation that allows me to move the moon closer to earth to see... consequences... duh duh duh <b>Justification:</b> See what happens to the earth an the moon if the moon came too
Proposal - Rotation of earth amy (5/13/2013 9:46:28 AM) >	
Proposal - My proposal cleo (5/13/2013 9:52:48 AM) >	
Proposal - Speed of planets owen (5/13/2013 9:48:32 AM) >	
Proposal - Moon closer earth ashleigh (5/13/2013 9:49:27 AM) >	
Proposal - Equator and polls julian (5/13/2013 10:18:40 AM) >	
<a href="#">New Proposal</a>	

[New Inquiry](#) [New Experiment](#)

---

**New Inquiry Note about Moon closer earth**

Headline... [Share](#)

What new information have you observed, measured, or read about?

What resource(s) did you use to learn this? (e.g. simulation name+URL, book title+author, information website name+URL, etc.)

---

**New Experiment about Moon closer earth**

Headline... [Share](#)

**Question:**  
What question are you investigating?

**Hypothesis:**  
Make an educated guess about how this works!

**Method:**  
How you will test your hypothesis?

**Results:**  
Share all your observations and/or measurements from your experiment.

**Conclusions:**  
Analyze your observations and/or measurements to see if your hypothesis is true or false!

Figure 72. Top: Tablet display for adding a new Report. If a student wishes to pursue this proposal (headlined “Moon closer to earth”), she can record her findings either as a “New Inquiry” report (*middle*), or as a “New Experiment” report (*bottom*).

## **Making Knowledge Accessible**

In managing the inquiry workflow and promoting awareness, CK helped to scaffold the KCI model. Students were enabled to collectively create a knowledge base that served as a resource for ongoing inquiry in astronomy, where Brainstorms become resources for Proposal creation, and Proposals defined subsequent astronomy investigations. CK made students' ideas accessible in the form of a visible and dynamic community knowledge base where notes could easily be found, read, and improved upon; through build-ons, additional notes or voting mechanisms.

In iterations 1 and 2, the community knowledge was accessible through the shared visualizations on the Common Board and tablet displays. These were used by the teacher, in sorting piles of similar notes on the Common Board, reading and revoicing notes, and discussing the contents with students. They were accessible to the students in the tablet-based readers, which revealed authoring, voting, build-on, and tagging information.

In iteration 3, a more explicit approach was taken to making knowledge accessible. In bucket tagging, students were provided automatically with brainstorm notes to tag, and were excited to see their note appear on the Common Board with a tag line, once they had done so. After the teacher had pressed the "Propose" button, students selected one of the four tag groups, logged in, and were automatically provided with only the relevant brainstorm notes (i.e., that had been tagged with their chosen topic). In this way, CK was helping to ensure that the knowledge base was accessible to students within the context of the inquiry script. Similarly, in the *Investigate* phase, all notes added by students appeared in their distinct Topic Board, as well as color coded on the Common Board. This was a means for CK to ensure that students were working with the relevant knowledge elements at that stage in the inquiry script.

## **Teacher-Guided Discourse in the Classroom**

Enactment analyses for all three iterations of CK revealed the Reflect-Refocus-Release (3R) orchestration cycle, and four discourse orientations. In iteration 2, a spectrum of interesting discourse moves including those that served to revoice student ideas, ascribe roles to students, and help motivate synthesizing discussions.

### **3R Orchestration Cycle**

Although the teacher's role was outlined in the technology and activity scripts, teachers had full autonomy in how they chose to orchestrate their CK-mediated classroom activity. The 3R (Reflect Refocus Release) orchestration cycle consistently emerged through all three iteration enactments. The continuous move back-and-forth between student-driven activities in the CK environment (Release) and community discourse events (Reflect), each informing the other, was guided by teachers' refocusing instructions. These refocus instructions made an impact, as CK notes from iteration 1 and 2 enactments in both classes were found to be congruous with teachers' refocusing instructions. A similar enactment analysis of iteration 3 was not possible because nature of inquiry was different - students pursued a wide variety of student-defined inquiry topics, and teachers' refocusing instructions in this iteration focused on epistemic approaches to knowledge and inquiry work, rather than on the subject-matter itself. However, note contributions consistently increased following teachers' refocusing instructions (i.e. in subsequent student-driven inquiry in the CK environment). Such CK-mediated knowledge workflow disrupts the traditional I-R-F (teacher initiates, student responds, teacher follows-up) discourse patterns that a teacher engages in with students in serial fashion; and summons Pea's (1994) notion of transformative communication:

The initiate in new ways of thinking and knowing in education and learning practices is transformed by the process of communication with the cultural messages of others, but so, too, is the other (whether teacher or peer) in what is learned about the unique voice and understanding of the initiate (Pea, 1994; p. 288).

### **Emphasis on Discourse Depends on Inquiry Task Demands**

An interesting shift in orchestration patterns was revealed when the amount of time that teachers spend on discourse versus student-driven activities was compared between iterations 2 and 3. Teachers gave more time overall to to community discourse (CDE) than to student-driven inquiry activities (SD-CK) in iteration 2 enactments. However, in iteration 3 enactments, teachers gave more time to student-driven inquiry activities and less time to reflective community discourse. One possible explanation is that iteration 2 was more content-oriented (i.e., WallCology investigations) while iteration 3 was more process-oriented (i.e. student-driven astronomy inquiry), with no predetermined content or referent for discourse. As such, discussions during iteration 2 enactment were more content-oriented, and less process-oriented; and discussions during iteration 3 enactment were more process-focused, looking for patterns and connections within the knowledge base. Since the specific content matter of iteration 3 was more student driven, teacher spent more time in small group interactions with student collaborators working on common inquiry goals. This resulted in more orchestration time given to student-driven inquiry activity in the CK environment (i.e., Release), and less time given to community reflection discussion.

Another possible explanation may be that CK itself was more structured, in terms of scaffolding the inquiry progression, placing a different set of needs or requirements on the

teacher, and supporting students more explicitly in terms of what they were supposed to be working on (i.e, within the various phases). Thus, different allocations of time and different emphases (discussed in next section) may have emerged within the activity system.

### **Four Discourse Orientations**

Teachers' discourse moves during community discourse episodes in all three iterations revealed the presence of four discourse orientations: community instruction (CI), community reflection (CR), teacher reflection (TR), and individual reflection (IR). Upon closer examination of these orientations in iteration 2 enactments, several inquiry discourse scaffolds (i.e. the orientation sub-codes), including types of revoicing, emerged for each orientation. Iteration 3 analysis focused on the orientations themselves, rather than on the inquiry discourse scaffolds. When the proportion of time given by teachers to the four orientations was compared between iterations 2 and 3, some interesting differences were seen. Teachers shifted in the level of Whole-class reflection (CR) they employed, as well as the degree of Classroom Instruction (CI). CI orientations increased for sessions that were transitioning from one phase of inquiry to the next – which is not surprising, given that some amount of direct instruction was needed to show students how to use the new technology tools related to the changing inquiry phase.

Segmentation and coding of discourse events in iteration 2 provided more detail about the specific role of discourse within the four orientations. In Teacher Reflection (TR) segments, for example, teachers were seen to model “knowledge work” processes by conducting their personal sense-making aloud. This calls to mind the notion of cognitive apprenticeship (Collins, Brown, & Holum, 1991) – teachers as master knowledge workers modeling for the students, set within a real-world inquiry context, of the community's inquiry.

Another prominent function of the TR orientation was to empower students. One empowering move was teachers' casting of students into roles, such as legitimate questioners, observers, and theorizers. Teachers also used TR to legitimize students' contributions by asking them for further elaboration, sometimes following-up by paraphrasing the student's elaboration and fusing it with their own phrasing towards a purposeful conceptual direction, then ending with a question back to the student, asking for validation. The student would be thus "empowered" to evaluate the teacher's revoicing. Such common forms of discourse exchange between teachers and students is similar to Polman's (2004) notion of dialogic activity structures – verbal exchange sequences suited to project-based learning environments.

Discourse within the CR and IR orientations was used to empower students by positioning the community or an individual student to make conceptual connections between multiple sources of ideas and information. Such scaffolds were often followed-up by a teacher's revoicing (TR) of such synthesis knowledge work. In a few cases of CR and IR discourse, the teacher asked the community or an individual to comment on the community's current epistemic approaches or progress, or to suggest new approaches. Such cases would obviously only occur when the situation was ripe for them, and the teacher was ready for it (i.e., in terms of the orchestrational demands). More often, teacher reflections were focused on making productive solicitations for student clarification or elaboration of CK notes, or trends within the knowledge base. Reflection on progress was also fairly common, preceding refocusing instructions for upcoming epistemic approaches that were issued by teachers during a CI-oriented discourse segment.

Because iteration 3 enactment analysis focused on the four orientations themselves, rather than on the inquiry discourse scaffolds (i.e., subcodes of the 4 orientations), and because the

scripts were so different between the two iterations, it was not practical to perform a comparative analysis of the specific scaffolds within the orientations. Future research could further explore the “Inquiry Discourse Scaffolds” identified for iteration 2, to see if there are new ones, or how the usage patterns may have differed.

### **Adding Non-Technological Scaffolds to CK**

When we were designing the CK scripts – particularly in iteration 3, which was considerably more open-ended about what would actually transpire – it was clear that teachers might need to develop spontaneous forms of non-technological scaffolds, using chalkboards, whiteboards, paper, or any other tools and media that are common or uncommon to their normal practice. Seen through the lens of an activity system, we had placed requirements on teachers to execute a certain script or progression, and offered them one set of tools and rules (i.e., script) with which to achieve the objective. However, the likelihood that CK would be able to fill all the needs required, in terms of knowledge construction and supporting discourse, was quite low, particularly given that CK is being invented here, and there was little concrete knowledge about what kinds of interactions it would support. If we had required the exclusive use of CK, we would have had to allow the script itself to be more open, in terms of what kinds of interactions and knowledge work occurred. Instead, our designs with the teachers were fairly committed to a certain inquiry progression and adaptation of the KCI model. Hence, the particular tools and representations involved in the enactment would likely require some flexibility. Many teachers, including both of those involved in this study, are adept at inventing on-the-fly representations that serve their immediate pedagogical purposes. These occurred in all three iterations of CK, and deserve mention here, and further study in future designs.



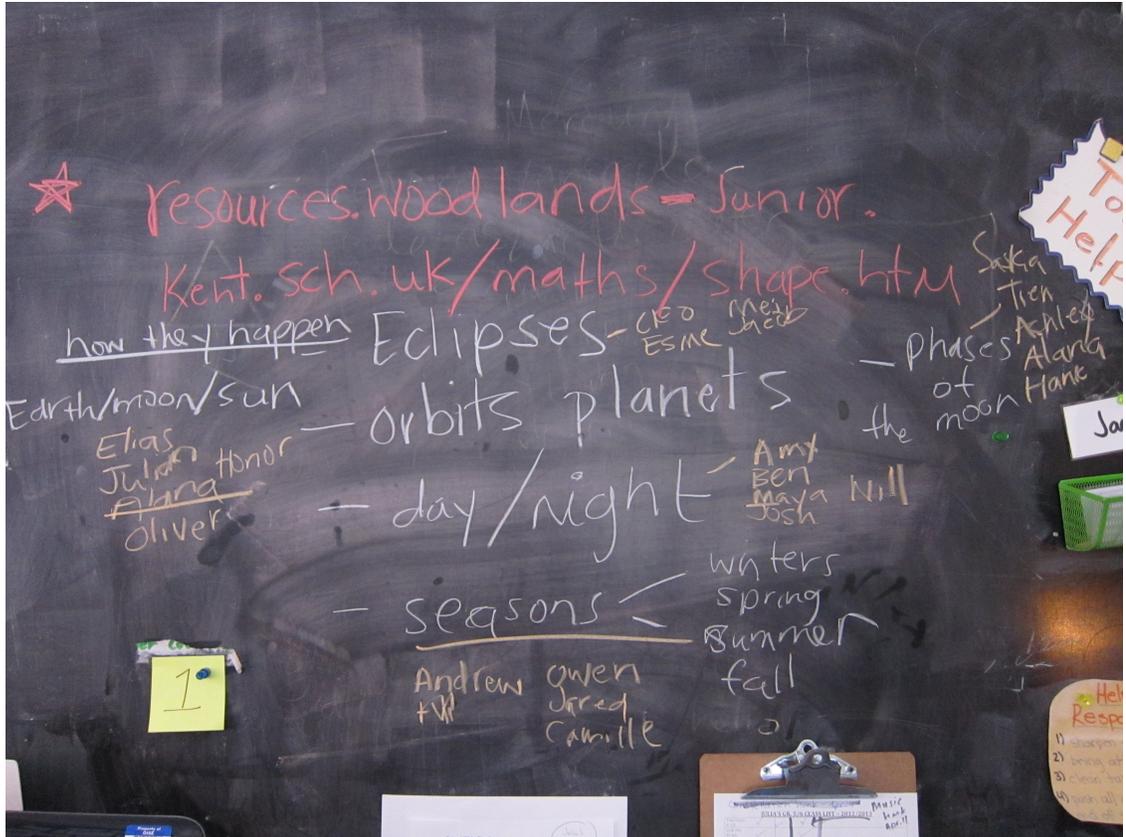


Figure 74. Emergent topics from Brainstorms, identified by Jen's class (written in white chalk by Jen).



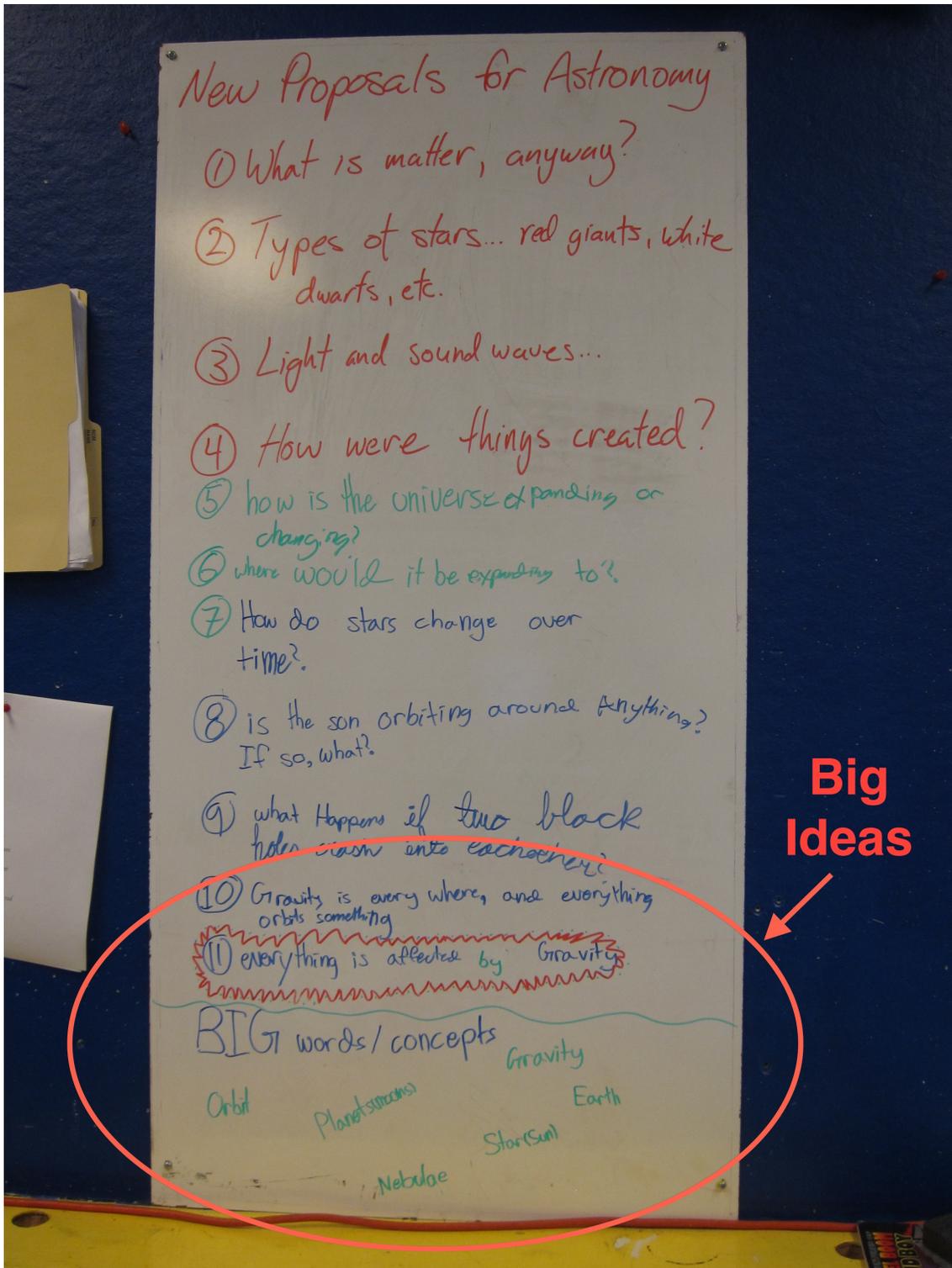


Figure 76. This board in Brad's classroom began as a record of "New Proposals for Astronomy" (red ink) prior to the start of the class session, and became a record of the community's knowledge convergence of big ideas and ongoing big questions during the culminating discussion.

## Addressing the Research Questions

I now return to the research questions articulated in the first chapter, summarizing the various outcomes of this study, in terms of how they can help respond to the questions.

### Question 1

*How do features of the Common Knowledge technology environment support inquiry-oriented discourse and progress within the knowledge community?*

A comparison of technology features in CK iteration 3 with Dillenbourg's (2013) five orchestration design principles (i.e., control, visibility, flexibility, physicality, and minimalism) demonstrated good alignment with these principles, such that CK can be considered as an "orchestration tool". That is, *CK served to share teachers' orchestration load*. One way in which it did so was to provide teachers a means of maintaining control of classroom management (e.g., the universal "Pause" button that suspends all tablet activity) and control of inquiry activity flow (e.g., teachers initiating inquiry phase changes by pressing a button on the Common Board). Perhaps the most significant support CK has to offer teachers to reduce orchestration load is the scripting of inquiry processes, including technology supports for moving students into a new phase, and moving the relevant knowledge objects from one phase into the next – all while preserving the teacher's role as critical in phase transitions (i.e., in monitoring and preparing students).

CK features helped to *make students' ideas and interactions visible* through dynamic visualizations of collective knowledge, including notes, tag relationships, word clouds, and aggregate vote results. In an effort to reinforce the conceptual relationships between notes, facilitate efficient information retrieval and reduce cognitive load, visual effects such as colour

coding and connection lines (e.g., joining notes to associated tags or joining Proposals to associated Reports) were used to emphasize note-tag and note-topic relationships. Movable note icons on public displays as well as tag nodes that doubled as note filters afforded topic-based note clustering and options for minimizing visual clutter. The CK Topic Boards served to visually and spatially distribute the community's four main interest topics, including the Proposal-Report relationships. These interfaces focused users' attention on and awareness of the inquiry activity at hand, providing a persistent channel of information about community progress and the content of the knowledge base. The Topic Boards prominently displayed topic names and all relevant content within a topic group, serving to make that group's progress visible. Students' tablets also provided visual feedback about the type of note they were creating (e.g., Experiment Report), the components of the note and (if applicable), the particular parent note to which theirs might be responding.

Another feature of CK that supported teachers was its employment of *productive constraints* that served to limit and guide student progress through the script. Teachers did have flexibility in adapting the curriculum script to fit their classroom contexts, including what forms of exchanges to hold with individuals, small groups and the whole class, or when to move on to the next inquiry phase. However, the CK technology environment also provided some helpful structures and restrictions, such that teachers and students perceived clear progress and a forward direction. While inquiry trajectories were certainly open to the particular interests of students, they were also constrained in some ways, to ensure progress. For example, once the four topic tags had been set up, students were required to connect their inquiry to one of those four groups. The use of "negotiated topics" provided the class (and teacher) with a visible referent of progress, helped provide referent for discourse and offered a continuing source of informal or ambient feedback.

Using carefully designed information flow, visualizations, and visual arrangements, CK guided student inquiry while trying to avoid over-scripting or hindering the development of student ideas. This was intended to reduce the complexity of the task, and corresponding cognitive load for teachers and students, while at the same time supporting their productive knowledge work. For example, removing the brainstorm notes in the final *Investigate* phase of iteration 3 was a response to the previous iteration, where teachers had complained that – even with tagging and filtering – the “cloud” of notes had gotten too voluminous and unwieldy, such that neither students nor teacher could ascertain the key ideas or current directions. Clearly, there are trade-offs in removing some of the content, but this “productive constraint” aspect of CK was one of the topics of research. Our hope was that students would not miss having their brainstorm “fodder” on the screen if we made sufficient efforts (i.e., within the script) to ensure that proposal notes had captured and responded to all the key ideas and directions from the brainstorm notes.

The multimodal nature of CK *supported physical interactions* for multiple social processes, including the student tablet displays, which were portable, touch-able, and often passed back and forth between students, peers and teachers. These were quite distinct from fixed workstations or even laptops, and played a strong role in facilitating individual and small group work. Small groups were often seen placing multiple tablets side-by-side to view multiple CK notes, or to juxtapose CK notes with laptop displays of simulation and online reference materials. The large-format Common Board on the classroom’s IWB was used as the physical hub of the community’s collective knowledge base and served as common referent to ground community discussions. During work periods, small groups and individual students would frequently approach the Common Board to interact with the notes and tag nodes, and the teachers often gathered small groups around the Common Board where they physically interacted with the

knowledge base. Similarly, the Topic Boards served as physical hubs for each interest group, facilitating the distribution of students and materials according to interests, and encouraging dialogue and collaboration between students within and between groups. These Topic Boards provided students with a sense of progress at-a-glance in the various groups.

## **Question 2**

*How can a note-sharing environment such as Common Knowledge be integrated into a sequence of inquiry activities to support progress?*

Sequencing of inquiry activities to support community progress requires careful combination of a technology within an inquiry script, serving to *manage the workflow, promote awareness of process and knowledge product, and make knowledge accessible as a resource for inquiry*. CK supported collective knowledge construction by providing a repository for students' ideas, then redistributing these ideas (i.e., according to the script) for further processing by the community. Throughout the script, CK represented the current inquiry activity, helping students and teacher maintain awareness of the inquiry process, and situating students' CK work in relation to the ideas within the community knowledge base. Student ideas were made visible and movable (i.e. on the Common Board), enabling teachers and students to easily access these ideas and recombine or cluster them with other ideas.

Another important outcome of this research is that *a pedagogical model such as KCI can inform the development of the inquiry script, as well as technological features of CK*. By tightly coupling the technology and inquiry script, in accordance with a structural model, students can be scaffolded to work as a knowledge community to create a community knowledge base which is subsequently used as a resource for scaffolded inquiry activities, indexed to specific and

assessable learning goals. Comparison of CK's third iteration design and enactment with KCI's four principles reveals that *this third iteration enactment met three of KCI's four principles*. Further examination of the content of CK notes and students' culminating media presentations is needed to determine if students' work did indeed align with the topics of gravity, scale, and nested systems; to determine whether all the KCI principles were met. Moreover, further study of students' epistemic commitments would be necessary to determine if they were focused on the progress of the community or just on their own specific inquiry topics. The teacher's role within KCI and in using the CK environment will remain an important topic for further research, as well.

### **Question 3**

*What forms of teacher-guided discourse are important to the successful application of community note-sharing environments in elementary classrooms?*

In a CK-mediated classroom, students engage in autonomous inquiry in an online notes-based environment and in teacher-guided discussions in the classroom environment. The inquiry work done in one learning environment affects the knowledge work done in the other, and vice versa. In all three iterations of CK, we observed that *teachers utilized an orchestration cycle of Reflect, Refocus, Release (3R)* as a means of managing this complex balance. Teachers' refocusing instructions were critical in guiding inquiry work done in the CK environment, and the work done in the student notes was vital to informing teachers' whole class reflections.

An interesting shift in the allocation of instructional time occurred between iteration 2 and iteration 3 enactments, evidently as a result of the differing forms of inquiry in the two enactments. Iteration 2 was more content-focused, with teachers allocating more time for

community discussion (i.e., Reflect) and less time for independent student work periods (i.e., Release). Iteration 3 was more process-focused, with teachers allocating less time for community discussion, and more time for independent student work periods. This suggests *discourse patterns/structures vary with inquiry task demands*. Perhaps teachers felt a greater need to guide student inquiry differently in both cases – spending more time in small group interactions during students’ work period, to guide the process-focused third enactment.

Alternatively, or in addition, there were substantive changes in how CK helped to orchestrate the progression of inquiry phases in the two iterations. In iteration 2, the teacher was solely responsible for coordinating the progression, leveraging content from student notes and observational data (i.e., in Wallcology software) to motivate a move into new inquiry phase. In iteration 3, however, CK played a more structural role, where teachers still needed to process the content of student ideas and guide discussions, but then took advantage of technology features to advance students into the next phase. There were a sufficient number of differences between the two iterations, where the respective activity systems would clearly produce quite distinct patterns of interactions and discourse.

Teachers’ discourse moves during community discourse episodes in all three iterations revealed the presence of *four discourse orientations: class instruction (CI), community reflection (CR), teacher reflection (TR), and individual reflection (IR)*. Teachers used TR discourse orientations to model their knowledge work processes as they interacted with students’ CK note contribution. Such processes may begin with identifying common themes, unique perspectives, and knowledge gaps, then move into relating ideas to prior knowledge or prior experiences, assessing the community’s current epistemic approach, and suggesting a new epistemic approach. Teachers also used TR discourse orientations to amplify students’ ideas in the public

sphere, revoicing ideas – sometimes fusing this with their own phrasing toward a purposeful direction – and seeking student validation of, or response to their particular revoicings. Such discourse moves can be seen as disrupting the traditional teacher-student power dynamic, since the student is now positioned to evaluate what the teacher said. CR and IR orientations were often employed to empower students through role-casting individual students (IR) or the community-at-large (CR) as legitimate participants of inquiry (e.g., questioner, observer, theorizer, inquirer), while simultaneously seeking students' explanations of what they had shared in CK notes or comments. CR and IR orientations were also used, less frequently, to encourage students to verbally build-on an idea, synthesize multiple ideas or multiple CK notes, comment about the current epistemic approach, or suggest a new epistemic approach.

Once again, there were observed differences in discourse patterns between iterations 2 and 3, in terms of the degree to which the teachers used each of the four orientations. A substantial reduction in the use of IR and CR orientations was seen in iteration 3, accompanied by an increase in community instruction (CI) and teacher reflection (TR). These different patterns are also likely a consequence of shifting task demands across the two iterations. Teachers, in their discourse, must move the class through the inquiry script, using the technology environment as an orchestrational tool. In the time between iterations, designers made profound changes to the activity system, in terms of the technology features and inquiry script, which will clearly impact on the forms of discourse arrived at by the teachers as they try to follow the pedagogical script.

### **Limitations of the Research**

Some limitations of this research are related to the tensions between supporting students in autonomous inquiry while also scripting their overall progression. Other limitations are

intrinsic to note-sharing environments as inquiry mediation tools in a face-to-face classroom. Finally, some limitations relate to difficulties that arose in the technology development and execution of the research. Sections below discuss these limitations, in turn.

### **Tensions Between Supporting Autonomous Student Inquiry and Scripting Procedural Inquiry Elements**

The three iterations of CK had differing levels of scripting, which were focused on differing priorities. Iterations 1 and 2, with their integration with the HelioRoom and WallCology investigation tools, were focused on student investigations of the embedded phenomena. Because iteration 2 lasted for 10 weeks, our script imposed a cumulative progression through the student investigations contained within the various WallCology technologies. In contrast, the iteration 3 script was not dedicated to any particular content or object of inquiry, and was rather based on teachers' preferred approach of knowledge building processes, imposing a cumulative progression through phases of increasingly focused inquiry. Teacher feedback on iteration 3 indicated they thought students' inquiry was constrained by the rigidity of selecting four topics of inquiry that emerged early in the unit. Hence, iteration 3 prioritized the scripting of inquiry progression, with autonomous student inquiry fitting within the various phases. Focusing on the effort to scaffold students' progression may have come with a trade-off in terms of the breadth of their investigations. While minimally guided inquiry has been argued to be less effective and efficient than guided inquiry (De Jong, 2006; Kirschner et al., 2006; Klahr & Nigam, 2004), teachers did remark about this trade-off, and it is important to keep it in mind in any future design efforts.

One component of CK that may help respond to this tension is the use of intelligent advisors that guide students as they engage in inquiry activities and reflections. Such agents would be technologically reminiscent of the “Task Advisors”, “Cognitive Advisors”, and “Social Advisors” of the SCI-WISE project (White et al., 1999), and pedagogically reminiscent of the “procedural facilitation” approach used by Scardamalia and Bereiter (1994) in their writing interventions (e.g., that involved showing students a flashcard of a particular writing strategy that addressed their immediate writing challenge, and gradually fading the flashcard support as a student internalized these strategies).

### **Limitations of Note-Sharing Environments as Inquiry Mediation Tools in F2F Classrooms**

Classroom observations of the 3 iterations revealed that students enjoyed exploring the embedded phenomena, as well as the various hook activities (e.g., Stellarium, or modeling activities), and any other inquiry of their own designs. They also clearly enjoyed exploring new ways of conducting such explorations. However, the time students used to share their ideas, questions, and new understandings in the form of CK notes clearly took time away from their engagement in the inquiry itself. The touch keyboards on tablets were frustrating for students to use, and the user interface was sometimes confusing. Indeed, there were times when teachers felt students could be more engaged in hands-on activities. While there has been a significant amount of research supporting a positive connection between the processing of scientific knowledge and the act of writing about the knowledge (Syh-Jong, 2007; Klein, 2004; Mason, 2001; Rivard & Straw, 2000; Keys, 1999, 1994; Holliday, Yore, & Alvermann, 1994; Scardamalia, Bereiter, & Steinbach, 1984), it can be difficult to convince inquiry-oriented teachers that students should be spending considerable time on reflective note composition. CK

responds to this by allowing flexible, multimodal access to the reading and writing of notes, and its asynchronous nature allows for integration with other inquiry activities. This allows knowledge communities a common repository of their emergent understandings, so that they do not have to go through the trouble of searching multiple modalities to access and refine their collective knowledge base. Furthermore, the web-based nature of CK offers students the possibility of accessing and contributing to their community knowledge base outside of the school day, extending students' learning to other contexts.

### **Limitations in Technology Development and Implementation**

Between iterations 2 and 3, the CK technology was re-implemented in a new software architecture, which necessitated much redevelopment for even the simple CK technology features like writing a note, or tagging. Thus, CK features were being developed to implement the design, which was itself an object of great negotiation. Once the design was settled, our technology developers made every effort to implement the features. However, we found ourselves in the familiar territory of developing features in the order in which they would be needed, with the final working product often available only a short time before the classroom enactment. With the technology development often a mere week ahead of the needed technological functions for classroom enactments of iteration 3, there were inevitable snags and delays, which in turn pushed back on other aspects of the design, like the script. In such cases, we would typically add a low-tech or no-tech activity, such as the hands-on solar system modeling activity described in Chapter 4.

On some occasions, students and teachers used CK technology in ways that were not anticipated, revealing new forms of interactions that would open up challenges or opportunities for the researchers. In general, it seems a good idea for teachers and researchers alike to

maintain a light grip on any planned sequences, maintaining contingency plans, responding to any issues, and taking advantage of unforeseen opportunities.

There were also some challenges with regard to the school schedule, as well as teachers' own schedules. In one class, the teacher decided to have the students continue with the Brainstorm phase a little longer, then engaged them in writing pre-Proposals. In the other class, students worked on brainstorm and pre-proposals for several days at one point, as a result of several successive teacher sick-days. Student motivation could be affected by such pacing issues, or if technology was behaving badly. Throughout the enactments, we worked with teachers to monitor students' motivation and engagement, and debriefed concerning possible responses to any situations. Still, it seems that 2-month curricular units are likely to encounter snags and disruptions, especially if (as in our case) there is a need to adhere to a planned pedagogical progression.

### **Limitations of Design-Oriented Research**

One necessary component of design research is an authentic classroom context, for which a learning innovation is iteratively designed, and in which the innovation is investigated (Cobb et al., 2003; Design-Based Research Collective, 2003). Yet such contexts are unique to each classroom, hence the findings of such research have limited generalizability. This is particularly true of interventions such as the present case, where a new digital learning environment is layered atop the existing classroom context, producing a truly unique hybrid environment. To study the impact of the 3R orchestration cycle or the four discourse orientations on student learning outcomes would require either a second trial where the same teachers and students performed a different script with a different technology layer (i.e., to determine the potential benefits of those identified here), or a comparison across teachers who shared nearly identical

contexts but deliberately varied in their approach. As such controls were not realistic for this research, no such comparisons could be made in terms of the relative advantage of using CK or certain discourse patterns to impact student learning. Furthermore, since so many aspects of the instructional context are dependent on the design, the discourse patterns themselves only emerge in direct relation to the specific technologies, scripting elements, and various “extrinsic constraints” (Dillenbourg et al., 2013) of the enacted curriculum (e.g., students’ needs, curriculum content, school-based scheduling, teachers’ energy constraints, classroom space constraints, technology development time constraints, etc.). Hence, a fundamental limitation of this research, as in most design-oriented studies, is the difficulty of applying any comparative methodology.

### **Directions for Future Research**

The tensions between (1) supporting autonomous student inquiry, (2) scripting procedural elements of inquiry, and (3) mediating this inquiry with a note-sharing technology are complex. Finding the right balance is essential if CK is to foster children’s collaborative inquiry and knowledge construction and help teachers orchestrate and engage student ideas. We have learned much from iterations 2 and 3, particularly about the sharing of orchestrational responsibilities between teacher and technology environment.

As discussed in the previous section, supporting autonomous student inquiry within a scripted technology-mediated inquiry progression may have come with a trade-off in terms of the breadth of their investigations. Future research into the use of intelligent advisors that guide students as they engage in inquiry activities and reflections could allow for a more flexible script, possibly minimizing this trade-off. Furthermore, this study’s content analysis of students’ CK notes focused mainly on their inquiry productivity and congruity with teachers’ revoicing

instructions (iterations 1 and 2), and on their congruity with ideas that had emerged in previous inquiry phases (iteration 3). The primary goal of such analyses was to determine if the collective inquiry was progressing, by uncovering the extent to which teachers' orchestrations impacted the student progress, and – in the case of iteration 3 – to see if CK was able to support the carriage and application of knowledge from one inquiry phase to the next. However, future research should examine the content of student notes more deeply, to determine their subject-matter and conceptual sophistication, as a measure of student achievement localized to this study's particular learning context and interventions. By examining the content of students' CK notes, particularly from the third iteration, in addition to students' culminating media presentations, it would be possible to determine the extent to which KCI's third principle was met (i.e., students' inquiry addressed targeted science learning goals).

One continued area of research should be concerned with new orchestrational supports for teachers. Although CK technology was designed to guide knowledge communities through a phased inquiry progression while affording students autonomy within these phases to drive their own inquiry trajectories, it is important to note that CK's technology and script design assumed an important role for the teacher as orchestrator of the technology and inquiry activity. Indeed, enactment analyses confirmed teachers' crucial role in determining the pacing of the script, coaxing community inquiry trajectories toward productive directions, and guiding the community's epistemic approach. Supporting teachers in their role as orchestrator would relieve some of their orchestration load, so that they could devote more of their attention to the conceptual dimensions of the inquiry at hand. To this end, using technology to increase teachers' awareness of the community's ongoing state of knowledge, in terms of "where they were" and "where they are", can better equip teachers in their scaffolding of the community inquiry towards productive "where they are going". Perhaps such awareness would be enhanced

with technology tools that connect “where they are” with “where they need to get to” (i.e. teachers’ pre-planned assessable learning outcomes for the inquiry unit).

Another continued area of research related to orchestrational supports for teachers, would be to investigate the role of specific features of CK in teachers’ orchestration. While my enactment analyses mentioned when teachers used the various notes or features of CK, they did not go into any detail about the nature of teacher use of these features, nor did they perform any comparative research (e.g., by varying the forms or content of teacher scaffolds). Closer examination of the four teacher discourse orientations (i.e., community instruction, community reflection, individual reflection, and teacher reflection) would yield further insight into the role of discourse in teachers’ scaffolding of collective inquiry in these classroom activity systems; where teachers and students continuously interact with a multimodal note-sharing system, the community’s collective knowledge base, the inquiry at hand, and each other.

The iteration 3 CK technology and script contained some features – “productive constraints” (Slotta, 2013) – to intentionally limit idea diversity at certain times and slow down inquiry progress at other times. Limiting idea diversity by allowing untagged Brainstorm notes to “disappear” after bucket-tagging, and having Brainstorm notes “disappear” with the launch of the Investigate phase; served to focus the community’s attention on ideas in the collective knowledge base that were relevant to the socially-negotiated topic categories of this knowledge base. Slowing the community’s inquiry progress by engaging students in synthesizing brainstorm ideas into Proposals for subsequent investigation, instead of allowing students to pursue inquiry with every small question or idea shared through individual Brainstorm notes; gives students an opportunity to consider their peers’ ideas that are developing temporally alongside with their own, reflect on how the collective ideas may connect or form a “big idea”,

and thoughtfully formulate a plan for investigating this big idea/question. While the notion of productive constraints may initially sound counter to the research goals, and counter to sound learning pedagogy more broadly, ‘productive constraints’ is an intriguing notion, and further research into the efficacy of productive constraints interwoven into a collective inquiry script supported by a multimodal note-sharing technology would provide useful insight for research in technology-scaffolded collective inquiry.

## **Conclusion**

Enactment analysis of our CK iterations showed that the teachers employed a 3R (Reflect Refocus Release) orchestration cycle to facilitate sense-making amongst students about the community’s knowledge base, and to guide student-driven inquiry. Indeed, teachers’ refocusing instructions, given at the end of a discourse episode, typically grew in response to the knowledge work accomplished during the discussion, as teachers worked with students to clarify what had been said so far, what directions were interesting or important, and how the class should think about moving forward. Teachers guided community *reflection* during discussions through discourse moves of four orientations: teacher reflection, individual reflection, community reflection, and community instruction. A closer look at the content of discourse segments revealed several interesting dynamics used by teachers to help students norm their views towards disciplinary practice, clarify positions, and reflect on possible interpretations. Teachers frequently used revoicing techniques, and cast students as primary knowers in active discourse roles to help move the discussion forward.

By engaging students in reflective note-sharing as part of a scripted inquiry progression, we were able to investigate how CK could help students and teachers engage in a Knowledge Community and Inquiry (KCI) approach. By adding CK as an inquiry scaffold, we produced a

hybrid form of learning environment, where individual students develop and share their inquiry work within a common digital repository, motivating teacher-guided discussions, which in turn motivate new, refocused inquiry using CK. The note-sharing system becomes a mediational tool between the two learning environments: students' collective inquiry done in the digital note-sharing environment and community knowledge work done during teacher-guided classroom discussions. Successful mediation of this hybrid learning environment entails the orchestration of and strategic guidance of the community toward inquiry progression. Hence the note-sharing system serves a dual purpose: as a mediational tool between inquiry learning environments, and as an orchestration tool to support teachers' orchestration of the learning progression.

Co-design and classroom enactment of three CK iterations have revealed that there are complex tensions between (1) supporting autonomous student inquiry, (2) scripting procedural elements of inquiry, and (3) mediating this inquiry with a note-sharing technology. Indeed, a persistent challenge confronting KCI or other knowledge community approaches is concerned with how to “create a sense of autonomy, creativity and inquiry, without ‘overscripting’” (Slotta, in Fischer et al., 2013; p. 570). This study has explored the balance between these three tensions contributing insights into the design of Common Knowledge as a mediational and orchestration tool, with the aim of supporting collective inquiry in the science classroom. Ultimately, such environments will blend seamlessly with the physical and digital learning environments, supporting student knowledge work, and offering teachers new ways of interacting with students about their ideas and activities.

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## Appendix A: Student Information Letter

\* To be printed on OISE/UT letterhead

**To:** Students of [teacher's name] grade 5/6 class

**From:** Dr. James D. Slotta

**Subject:** [School's name] student participation in a University of Toronto curriculum study

Dear [school's name] student & parent/guardian,

As part of a new funded research project called *Knowledge Community and Inquiry with Embedded Phenomena*, I will be working with [teachers names] to add new activities to their science curriculum. The teachers, vice principal, and principal have approved of this study, and [vice principal's name] is a collaborator on the project. Most research activities will involve only normal classroom learning, similar to other inquiry oriented curriculum projects that have been used in [school's name]. This project will explore how to help students collaborate with peers to explore a rich multimedia simulation that is displayed within their classroom environment. The teachers will work closely with my research team, as well as other [school's name] teachers and administrators, to design curriculum activities and technology tools for this project. Examples of technologies we will use are wikis, simulations, tablet computers, and multi-touch surfaces. This study will help us understand how students and teachers can learn from such rich simulations and collaborative inquiry.

Occasionally, we will conduct short interviews with students to gain a deeper understanding about their experience and opinions, as well as their understanding of the science topics they are studying. Students will be asked to volunteer for interviews, and volunteers will require their parents to indicate consent on the Video & Interview Consent Form. We may also video record certain class periods, which would also require the consent of a parent or guardian. You may also be asked to complete a short questionnaire about science concepts at the beginning and ending of the lesson. Only your teacher and the research team will have access to any of the information collected within this research. At no time will your names, your teacher's names, or the name of your school be identified in published documents. All information that is collected will be kept in locked computer files, with student names and identities replaced by anonymous ID numbers.

Because the learning activities of this project will happen as part of the regularly scheduled class, they will not require any extra effort on the student's part. We will make sure this research does not interfere with students' learning experience, and will be working in closely with the teachers and others at [school's name] to ensure that the activities are a good fit for students. There are no risks associated with participation in this research, and students are free to withdraw their participation at any time. Student participation in this study in no way affects

their grade for the course. If the student elects not to participate, s/he will still conduct the activities (since they are part of the curriculum), but we will not look at any of that student's contributions within our own analyses.

Every effort will be taken to make sure the student's identity is kept confidential. Most of the information used in this research project will be in the form of computer-based materials that students create or modify during classroom activities. Student name will be visible to classmates, teachers, and the research group, but will not be available to anyone from outside the school. Our research team will work with these materials, but will never include student names or any identifying information in any of our analyses, reports, or materials. For our own internal reference to your information, we will replace student name with a random ID number. All information will be accessed from a secure database within my research laboratory. If students are asked for an interview, we will do so either before or after class, or when your teacher is not in the room. All interviews will be conducted between classes or immediately after school in the school library.

If there are any questions about the study, please feel free to contact me at: [telephone number] or [email address]. Any questions about your rights as a participant can be directed to the University of Toronto Ethics Review Office at: [ethics.review@utoronto.ca](mailto:ethics.review@utoronto.ca) or 416-946-3273.

Sincerely,

James D. Slotta

Associate Professor, Department of Curriculum, Teaching and Learning, OISE/UT

Canada Research Chair in Education and Technology

*Published study results will be made available for students and/or parents who are interested. Please feel free to contact the principal investigator with any questions or concerns: James D. Slotta, Associate Professor. OISE/UT, 252 Bloor Street West, Toronto, ON, M5S 1V6. Phone: [telephone number] Email: [email address]*

## **Appendix B: Parent/Guardian Interview and Video Consent Letter**

\*To be printed on OISE/UT letterhead

**To:** Parents/Guardians of [teacher's name] grade 5/6 class

**From:** Dr. James D. Slotta

**Subject:** Consent for video and interview as part of a University of Toronto research project

Dear [school's name] parent/guardian,

This letter is requesting your permission for your child to participate in a research study where we will be exploring a new form of technology-enhanced inquiry for science (see accompanying information letter). This project is part of a new collaboration between our research group at The University of Toronto and the grade 5/6 teachers at [school's name]. This project has been approved by Principal [principal's name], and by the Research Ethics Committees at The University of Toronto and [school's name] respectively. Vice Principal [vice principal's name] is a collaborator on the project.

Our research is concerned with the design of inquiry science activities for [school's name] classrooms that use multi-media materials and sophisticated simulations to encourage students as they come up with ideas and investigations. All curriculum is designed by [school's name] teachers, in collaboration with our research group. This will be our first time to try out some new "tablet" computers and simulations, with the goal of helping students work collaboratively in solving a science challenge. To help us understand how well the technologies and inquiry designs are working, we would like to videotape the class session, and to informally interview students about their impressions of the tasks and technology tools.

First, this letter requests your permission for your child to appear in a video as part of a regular classroom observation. The video will not focus on your child specifically, but rather the classroom experience, as a whole: how is the curriculum working, what are teachers doing as they engage with students, and how are students using the various technologies and materials that we've designed? The video camera will be directed only at students who have parental permission to be recorded.

Second, this letter requests your permission for a member of our research team to interview your child informally about his or her experience with those activities: "Were they enjoyable?" "Were they an effective way to learn?" "Did they help classmates collaborate with one another?" The interview itself will not impact your child's grade. Interviews will last approximately 10-15 minutes, and will be conducted between classes or immediately after school in the school library.

Your child's safety is *the highest* priority, and every effort will be made to protect your child's identity and whereabouts. No portions of this video will be published in any document or publicly available location (i.e., on the Internet). Video recording will only take place during regularly scheduled class time.

Your permission for your child's participation in an interview and to be video recorded, are strictly voluntary. Both interview and video data will provide an important source of information to our research team, capturing a rich description of what is happening, for purposes of informing our group's discussions and analyses. You or your child may withdraw your consent for your child to be video recorded at any time, and your child is free to withdraw from the interview at any time; if uncomfortable or inconvenienced for any reason.

If you consent to your child participating in an interview and/or being video recorded for this study, please return the attached permission form. You will be given a copy of this form for your reference.

If you have any questions or concerns about the study, please feel free to contact me at: [telephone number] or [email address]. Questions about your child's rights as a participant can be directed to the Ethics Review Office at: [ethics.review@utoronto.ca](mailto:ethics.review@utoronto.ca) or 416-946-3273.

Sincerely,

James D. Slotta

Associate Professor, Department of Curriculum, Teaching and Learning, OISE/UT

Canada Research Chair in Education and Technology

### Appendix C: Parent/Guardian Interview and Video Consent Form

\*To be printed on OISE/UT letterhead

Please complete and return the consent form below to your child's science teacher by **Friday, November 9, 2012**. *(Only ONE COPY of this page is required)*

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I have read and understood the details of the study outlined in this letter. By checking off the box(es) below, my child and I consent to the following:

- My child consents to appearing in video for this project, and has my consent for this.
- My child volunteers to be interviewed, and I consent to my child being interviewed for this project.

\_\_\_\_\_  
Name of Student (please print)

\_\_\_\_\_  
Name of Parent/Guardian (please print)

\_\_\_\_\_  
Parent/Guardian's Signature

\_\_\_\_\_  
Date

*Published study results will be made available for students and/or parents who are interested. Please contact the principal investigator at: [telephone number] or [email address]. Any questions about teachers' or students' rights as participants can be directed to the University of Toronto Ethics Review Office at: [ethics.review@utoronto.ca](mailto:ethics.review@utoronto.ca) or 416-946-3273.*

## Appendix D: Teacher Consent Letter

\* To be printed on OISE/UT letterhead

**To:** [Teacher's name], [school's name]

**From:** Dr. James D. Slotta, Associate Professor, OISE/University of Toronto

**Subject:** Letter of Consent to Participate in University of Toronto Research

Dear [school's name] teacher,

I am interested in conducting a research project in your class entitled: *Knowledge Community and Inquiry with Embedded Phenomena*. This project will explore how to help students collaborate with their peers to explore a rich multimedia simulation that is displayed within their classroom environment. As a teacher participant, you would work closely with myself and my research team, as well as other [school] teachers and administrators, to design curriculum activities and technology tools for this project. Different technologies will be used depending on the topic and type of activity. My research team will help you learn to use the technology and will sometimes come to your classroom to help out with the project. Examples of technologies we will use are wikis, online discussions, Web-based learning environments, simulations, tablet computers and multi-touch surfaces. This study will help us understand how students and teachers can learn from such rich simulations and collaborative inquiry.

Most research activities will involve only normal classroom learning, similar to other curriculum projects you have done at [school]. We will be helping to design exciting new curriculum with cutting edge technologies, and then observing students to see how they enjoy the activities and learn from them. Occasionally we will ask students for an interview to gain a deeper understanding about their experience, as well as their understanding of the relevant science topics. Students will be asked to volunteer for interviews, and will require their parents to sign a separate Interview Consent Form. We may also want to videotape certain class periods, in which event we would also give students a Video Permission Letter requiring parental signature.

Because the activities associated with this project will occur as part of your regularly scheduled class, they should not require any extra effort on your part. We will make sure this research does not interfere with your teaching experience, nor with the students' learning experience. And we hope to work in close collaboration with you and other teachers at [school] to ensure that the activities are a good fit for your classrooms. Some possible activities that we may consider for our curriculum design include: learning about and using new technologies, having discussions about science phenomena with your classmates; interpreting puzzling phenomena that appear around the classroom; and debating observational data. Students may also be asked to complete a short questionnaire about science concepts at the beginning and ending of the lesson. At no time will student names, teachers' names, or the name of your school be identified in published documents. All information that is collected will be kept in locked computer files, with student names and identities replaced by anonymous ID numbers.

There are no risks associated with your participation in this research, and you are free to withdraw your participation at any time. If you should decide not to participate, you will presumably still conduct the activities (since they are part of your curriculum), but we will not look at any of your students' contributions within our analyses.

Every effort will be taken to make sure your identity and that of your students is kept confidential. Most of the information used in this research project will be in the form of computer-based materials that you create or modify during your classroom activities. Your name will be visible to your students and to the research group, but will not be available to anyone from outside the school. Our research team will work with your materials, but will never include your name or any identifying information in any of our analyses, reports, or materials. For our own internal reference to your information, we will replace your name with a random ID number. All information will be accessed from a secure database within my research laboratory. **Although your name and the name of the school will not be used, there is a risk/possibility that your identity might be linked to reports from the study.**

A copy of this consent form will be given to you for your reference. If you have any questions about the study please feel free to contact me by phone: [telephone number] or through email: [email address]. Questions about students' rights as participants can be directed to the University of Toronto **Office of Research Ethics** at: [ethics.review@utoronto.ca](mailto:ethics.review@utoronto.ca) or 416-946-3273. Research results will be made available upon request.

Sincerely,

James D. Slotta

Associate Professor, Department of Curriculum, Teaching and Learning, OISE/UT

Canada Research Chair in Education and Technology

## Appendix E: CK Version 1 Post-Enactment Student Interview Questions

1. What have you just done today?
2. Did you have a particular goal for this class? Something you were trying to do?
3. How did your teacher introduce the HelioRoom activity?
4. Would you change anything about the design of the tablets or the big screen?
5. In terms of sharing your ideas with each other, did you feel the tablets helped you to do that or did you kind of have to wait for your partner? Or were you able to talk about things first and decide together what you wanted to put in?
6. How did you find using the big screen at the front? Did that help you?
7. You all do a lot of knowledge building here, using other technologies. If you think about your experience doing that and then think about the experience you had just now, would you call what you did just now "knowledge building"? Why?
8. Were there other ways you were sharing or getting information that felt like knowledge building?
9. Did the technology help or hinder the way you collaborate with each other? Why?
10. Could you summarize what you think the tablet technology did today, in helping you learn? How did the tablets make it better for you?

## Appendix F: CK Version 1 Post-Enactment Teacher Interview Questions

1. What was the instructional purpose of the News Activity? Is the idea of ‘play with the technology’ part of your regular patterns or routine in introducing new approaches or new ideas within your classes?
2. (a) How frequently do you discuss strategies and content with your teaching partners and other teachers within the school? Is this part of your school structure and process?  
(b) How important is this to your own practice? (Why?)
3. How did the debrief meetings immediately after the runs (implementation of activity), provide you with the evidence you require for student learning? How did it change your practice?
4. How did working within this research-school community influence your practice? How can we improve this process?
5. Because these kinds of inquiry activities are fairly complex in design, what kinds of technology supports could be designed to support teachers that would help them be more effective?
6. Going forward into the next iteration of this research project what are some of your questions?
7. How did you/(your teachers) promote collaborative learning and exchange for depth of student understanding, when using HelioRoom and the tablet-IWB (interactive whiteboard) app?
8. How did student discourse and collaboration change with the use of HelioRoom and the tablet-IWB app?
9. How did students’ inquiry learning change with the use of HelioRoom and the tablet-IWB app?

## **Appendix G: CK Version 2 Post-Enactment Student Interview Questions**

1. If you were going to describe what you did in the WallCology unit to a new student coming into Grade 5 next year, how would you describe what you and your classmates did?
2. Thinking back to the work that you personally did, what do you feel you became most expert at or “specialized” in?
3. What science concepts did you learn about?
4. What did you think about using the SMART Board the way that we did?
5. What did you think about using the tablets the way that we did?
6. How did using the Discussion Tool and the Common Board affect your knowledge building?
7. How did using the Discussion Tool and the Common Board affect your collaboration with classmates?

## Appendix H: CK Version 2 Mid-Enactment Teacher Interview Questions

1. How have the technology-mediated discussions added to your ability to engage students in knowledge building discourse?
2. What are some ideas you have for using the Common Knowledge discussions in the remainder of the unit?
3. What technological changes would better support your current Discussions approach?
4. How did the availability of the aggregate observations make an impact on the flow of learning and inquiry?
  - a. Observations of habitats and organisms
  - b. Observations about life cycles
  - c. Observations about relationships --> food web
5. What were some of your instructional pattern highlights for the first phase of Wallcology. Why did these stand out for you? What (and why) were some of the successes and challenges during Phase 1?
6. How did the debriefing meetings (Co-Design Meetings), lesson-planning sessions (before and after enactment), and the quick check-ins throughout Phase 1 of Wallcology impact the flow of your own classroom activities? How can we improve this practice?
7. How did the technological/pedagogical(KCI) design and the "design community" influence your own practice? (Has this had an effect on your extended school community)?

## Appendix I: CK Version 2 Post-Enactment Teacher Interview Questions

1. How have the technology-mediated discussions added to your ability to engage students in knowledge building discourse?
2. How did you combine oral discussions with technology-mediated discussions to facilitate idea growth in your class?
3. What are some ideas you have for using the Common Knowledge discussions in your future practice?
4. What technological changes would better support your future Discussions approach?
5. Did you feel that the "structured design" - the "scripting" of the flow of activities helped promote the development and progress of a community of inquiry within your classroom?
6. What kind of changes to the script (and how the script is coordinated or orchestrated by the teacher) would help foster better community development?
7. Can you identify how the aggregated representations impacted your instructional patterns when used
  - a. On the SMART Board, in whole-class discussions?
  - b. On the SMART Board, in small group discussions?
  - c. On the tablets, by the students?
8. When and why did you feel it necessary to move to paper artefacts to augment the knowledge building and/or student learning?
  - a. Laminated icons
  - b. Lab notebooks
  - c. Summary charts
  - d. Printed graphs for student annotation
  - e. Food webs
  - f. Counts (i.e. computations)
  - g. Other?
9. What were some of your instructional pattern highlights for the first phase of Wallcology. Why did these stand out for you? What (and why) were some of the successes and challenges during Phase 2 and 3?
10. How did the debriefing meetings (Co-Design Meetings), lesson-planning sessions (before and after enactment), and the quick check-ins throughout Phase 2 and 3 of Wallcology impact the flow of your own classroom activities? How can we improve this practice?
11. How did the technological/pedagogical (KCI) design and the "design community" influence your own practice? (Has this had an effect on your extended school community)?
12. When and why did you feel it necessary to divert from the lesson plan and schedule?

13. What is the one (or two) critical moment(s) that you remember from WallCology? And why do you remember this vividly?
14. What are some of the learning moments for you during WallCology?
15. If you had to describe the 'WallCology' story to your peers (or colleagues) what would you say and how would you describe it?
16. What was some of the important lessons learned from WallCology?

## **Appendix J: CK Version 3 Post-Enactment Student Interview Questions**

1. If you were going to describe what you did in the Astronomy unit to a new student coming into grade 5 next year, how would you describe what you and your classmates did?
2. Thinking back to the work that you personally did, what do you feel you became most expert at or “specialized” in?
3. What science concepts did you learn about?
4. What did you think about the SMART Board display of Common Knowledge? How did you use it for your learning? How did you use it to work with classmates?
5. What did you think about using Common Knowledge on the tablets? How did you use Common Knowledge for your learning? How did you use it to work with classmates?
6. What did you think about the Interest Group screens? How did you use it for your learning? How did you use it to work with classmates?
7. Can you tell me about the styrofoam ball, light, and dowels activity? How did exploring your theories with those materials help you to think about your topic (e.g., phases of the moon)?

## **Appendix K: CK Version 3 Post-Enactment Teacher Interview Questions**

### **Orchestration of Discourse for Collective Inquiry and Knowledge Advance**

1. During "Open Inquiry", what were some of your instructional patterns? What were the successes and challenges?
2. What, if any, alterations did you make in your instructional patterns to support your students in "Getting Ready for Structured Inquiry" (i.e. Proposal phase)? What were the successes and challenges?
3. What, if any, alterations did you make in your instructional patterns to facilitate your students in "Structured Inquiry"? What were the successes and challenges?
4. How did students advance ideas during "open inquiry", and how do these ideas guide activities in subsequent "Structured Inquiry"?
5. How did students connect their culminating projects to their "Structured Inquiry" discoveries?
6. How did the pedagogical (open inquiry > proposals > structured inquiry > culminating project) and technological (Common Knowledge) design affect your classroom community's astronomy inquiry?
7. How did the process of socially negotiating tags (open inquiry) which subsequently became inquiry topics/themes (proposals and structured inquiry), affect your classroom community's astronomy inquiry?
8. How did the 4 inquiry themes in your classroom connect to your curriculum learning goals for the unit?

### **Role of Discourse Technology in Collective Inquiry and Knowledge Advance**

9. Did you feel that the "structured design" - the "scripting" of the Common Knowledge flow of activities helped promote inquiry progress within your classroom community? What were the successes and challenges?
10. What changes to the Common Knowledge scripting of activity flow would help foster better knowledge community inquiry?
11. What role did Common Knowledge have in fostering whole-class, small-group, and individual inquiry?

12. How did you combine oral discussions with Common Knowledge discussions to facilitate idea growth and inquiry progress in your class? What technological features supported this?
13. What features of Common Knowledge added to your ability to engage students in their inquiry? (e.g., Common Board, Interest Boards, word clouds on, Inquiry voting on Proposal Notes, Connection voting on Inquiry Notes and Experiment Reports, etc.).
14. What technological changes (in terms of tools, not the activity flow) to Common Knowledge would better support your future approach to inquiry discussions?
15. What ideas might you have for using the Common Knowledge discussions in your future practice?

**Theorizing with Tangible Materials (Styrofoam balls, dowels, and lights)**

16. How did you feel the theorizing with materials activity provided students with an opportunity to develop conceptual understandings of inquiry topics? How did the activity fit in with the rest of the astronomy curriculum?