Reflective Structuration of Knowledge Building Practices with Idea Thread Mapper

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Abstract

This research examined the reflective structuration of knowledge building practices in two Grade 5/6 classrooms (A and B) that studied electricity over three months using Knowledge Forum, a collaborative online environment. Students in classroom A co-constructed collective structures of inquiry to support their ongoing interactions and contributions supported by Idea Thread Mapper (ITM), an online tool designed to make unfolding strands of inquiry visible in extended interactive discourse. Qualitative analyses of classroom videos and observational data documented the formation and elaboration of collective structures, which involved shared interpretative frames about the interconnected epistemic objects and the unfolding strands of inquiry in the community. The impacts of reflective structuration on knowledge building were examined through content analysis of online knowledge building discourse and student reflective summaries of what they had learned. With reflective structuration, students in classroom A made more active and connected contributions to their online discourse, leading to deeper and more coherent understandings of a broader set of topics about electricity. The findings contribute to understanding how agency-driven interactive actions and ideas from students may form into a coherent and productive system of knowledge practices and be sustained over time without extensive teacher pre-scripting.

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Introduction

Education in the knowledge society needs to prepare students for deep and creative work with knowledge. Over the past two decades, learning scientists have made major advances to explore how authentic inquiry and knowledge building processes may be enabled among students to achieve deep and productive outcomes. Extensive studies have examined the social and cognitive processes of inquiry-based learning and knowledge building, which include questioning, progressive problem solving, explanation, evidence-based testing of hypotheses and claims, collaborative discourse, knowledge integration, reflection, shared regulation of joint efforts, and so forth (e.g. Bell & Linn, 2000; Edelson & Reiser, 2006; Hakkarainen, 2003; Hmelo-Silver, 2004; Järvelä & Hadwin, 2013; Roschelle, 1992; van Aalst, 2009; Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007). With a general consensus that the inquiry-based learning needs to be supported to be effective, researchers have further examined how to facilitate the inquiry processes through teacher scaffolding and technological supports that provide procedures, scripts, and prompts for various processes and actions (Hmelo-Silver, Duncan, & Chinn, 2007; Kollar, Fischer, & Hesse, 2006; Reiser, & Tabak, 2014). Despite the conceptual insights and technological innovations developed, we, as a field, still face the challenge of how to bring sustained inquiry and knowledge building into classrooms to transform educational practices. To address this challenge, researchers highlight the need of a social practice perspective in collaborative learning research (Hakkarainen, 2009; Hakkarainen, Muukkonen, Markkanen, & KP-Lab Research Community, 2006; Stahl & Hesse, 2009), which will consider the above-mentioned idea-centered inquiry processes in conjunction with the cultivation of social practices that guide, channel, and sustain student personal and collaborative efforts in creative ways.

In authentic knowledge-creating practices, participants do not simply enact repeated procedures to accomplish given tasks but continually create and adapt their social practices as their knowledge is advanced (Knorr Cetina, 2001, Zhang, Scardamalia, Reeve, & Messina, 2009). To enable such dynamic social practice for knowledge building in school settings, a principle-based, as opposed to procedure-based approach to inquiry practices is needed (Scardamalia, 2002). Drawing upon the Knowledge Building pedagogy (Scardamalia & Bereiter, 2014), a renowned inquiry-based collaborative learning program to cultivate authentic knowledge-creating practices, our previous studies explored how students and teachers worked with a set of principles to co-design and improve their classroom practices and chart the unfolding course of inquiry and discourse (Zhang, Hong, Scardamalia, Teo, & Morley, 2011; Zhang & Messina, 2010). This line of research has led to the discovery of an important socio-epistemic mechanism enabling sustained knowledge building practices: In productive knowledge building communities, members not only build collective knowledge, but co-construct adaptive collective structures which provide members with shared expansive frames of their collective work including the high-potential objects of inquiry, unfolding strands of inquiry practices, and ways to pursue deep research and collaboration (e.g. genres of activities and norms of discourse) (Tao, Zhang, & Gao, 2016, 2017; Tao, Zhang, & Huang, 2015; Zhang, 2012, 2013). A technology tool—Idea Thread Mapper (ITM)—was designed to support students' reflective efforts to co-structure and monitor their unfolding strands of inquiry driven by interactive discourse over time (Chen, Zhang, & Lee, 2013). The current study aims to investigate the processes by which students co-construct and adapt collective structures of inquiry using ITM and examine the impacts of such efforts on student knowledge building.

In the sections below, we first provide a brief literature review of the Knowledge Building pedagogy and the social practices underpinning creative knowledge work. A conceptual framework is then introduced focusing on the reflective structuration of knowledge practices supported by Idea Thread Mapper.

Knowledge Building Pedagogy

This research examines co-constructed structures of inquiry in the context of knowledge building communities. Knowledge Building pedagogy attempts to transform education in line with how knowledge is created and processed in a knowledge society (Scardamalia & Bereiter, 2014). In real world knowledge-creating organizations, members continually build on and advance the knowledge assets of their community by generating and identifying promising ideas and improving the ideas through incremental and sustained processes; by formulating deeper problems as solutions are developed; by pursuing idea-centered discourse involving multiple perspectives, diverse expertise, and constructive criticism; by taking risks; and by assuming leadership and responsibility at the highest levels instead of relying on the leader to tell them what to do (Amar, 2002; Bereiter & Scardamalia, 1993; Dunbar, 1997; Florida, 2002; Sawyer, 2007). Knowledge Building pedagogy aims to bring authentic knowledge-creating processes into the classroom: Working as knowledge building communities, students engage in sustained idea improvement to collectively advance the “state of the art” of their community’s knowledge—their collective knowledge as a social product. They identify and work on problems of understanding, contribute their ideas to a public space, engage in progressive discourse and experimentation, and use a wide variety of resources to deepen and improve their ideas. A networked knowledge building environment—Knowledge Forum—has been developed to support the high-level knowledge processes. Within this networked environment, students create *views* (workspaces) in line with their knowledge goals, contribute ideas and questions by writing *notes* in the views, and build on and reference one another's notes for interactive discourse to advance their collective understandings.

In contrast to other inquiry-based learning programs in which students are required to work on predefined project tasks or problems using step-by-step procedures and scripts, Knowledge Building pedagogy encourages students to enact high-level epistemic agency and responsibility to progressively define their knowledge goals as the inquiry unfolds, contribute and advance ideas, monitor progress, and engage in long range planning to chart the processes of inquiry and collaboration (Scardamalia, 2002). An idea-centered and principle-based approach to classroom design is adopted to support students' participatory control and engagement. Student ideas, as opposed to activity procedures, are treated as the center of classroom life. Teachers and students co-construct and reconstruct the flow of inquiry processes as their work proceeds, guided by a set of knowledge building principles (Scardamalia, 2002) including: *authentic problems and real ideas, improvable ideas, epistemic agency, collective cognitive responsibility for community knowledge, knowledge building discourse*, and so forth. In each knowledge building initiative focusing on a core curriculum area and spanning across several months, students identify progressively deeper questions to drive their research and discourse, supported by experimental work and constructive use of authoritative sources (e.g., books). Students contribute their diverse ideas to the community, formulate deeper questions and goals, and create spontaneously formed groups to address the goals (Zhang et al., 2009).

A large body of research has been conducted to examine the processes and outcomes of knowledge building among students from Kindergarten and above (see Chen & Hong, 2016 for a review). The findings support the effectiveness of knowledge building and have further revealed essential patterns of student contributions and interactions underlying productive knowledge building. These include generating progressive chains of questions to seek explanations beyond factual information, theorizing and explaining, examining ideas using evidence, constructive use of readings, interactive idea build-on, integrating ideas for higher levels of conceptualizations, and ongoing reflection on collective advances and personal contributions (Chan & van Aalst, 2007; Chuy, Zhang, Resendes, Scardamalia, & Bereiter, 2011; Hakkarainen, 2003; van Aalst, 2009; Zhang et al., 2007, 2009; Zhang & Sun, 2011). Many of these patterns are consistent with the productive features of learning interactions captured by researchers in broader problem-based, collaborative learning settings (e.g. Damşa, 2014; Hmelo-Silver, 2003; Mercer & Littleton, 2007).

Despite the advances made in understanding the social and cognitive interactions in knowledge building and collaborative inquiry learning, we still face the challenge of how to bring these innovations to classrooms to leverage deep and sustained transformation of educational practices. Beyond understanding the specific social and cognitive processes of idea development, research on knowledge building and collaborative learning needs a social practice perspective, to incorporate a larger focus on the social practices enacted by students and their teacher to sustain and channel their cognitive and social moves for long-term productivity (Hakkarainen, 2009; Stahl & Hesse, 2009). Hakkarainen (2009) calls such social practices of working with knowledge “knowledge practices.” As he argues, “to truly contribute to educational transformation, pedagogical approaches have to be embedded in locally cultivated ‘knowledge practices’ that channel the participants’ intellectual efforts in a way that elicits collective advancement of knowledge” (p. 213).

Understanding Creative Knowledge Practices

Knowledge practices, as a special type of social practices, involve an array of goal-directed actions enacted by participants to work with epistemic objects, using various tools and drawing upon socio-historically developed systems of knowledge (Hakkarainen, 2009; Knorr Cetina, 2001; Schatzki, 2002; Scribner & Cole, 1981). Knorr Cetina (2001) calls the epistemic things for investigation in knowledge practices as “epistemic objects,” which are “are at the center of a research process and in the process of being materially defined” (p. 181). Epistemic objects differ from everyday conceptions of material objects (e.g. goods) in traditional social practices: Material objects are characteristic of closed boxes ready-to-hand or to-be-traded further; epistemic objects lack such “completeness of being” and have the capacity to unfold indefinitely. Epistemic objects are “characteristically open, question-generating and complex” (Knorr Cetina, 2001, p. 181), and are progressively defined as the knowledge practices unfold. Accordingly, recent research highlights the dynamic, creative, and improvisational aspects of knowledge practices beyond conventional notions of social practice as repetitive routines (Engeström, 2008; Sawyer, 2007; Williams & Yang, 1999; Zhang et al., 2009). Rather than relying only on mundane habits or routines (that may also be needed), knowledge practices are aimed at solving emergent problems and constant pursuit of novelty and innovation (Hakkarainen, 2009). Therefore, members do not merely work on predefined objects of inquiry following routine procedures, but construct their own ways of working with ideas when needed, contributing to the development of new adaptive structures. They define new and deepened goals as their work proceeds, frame new frontiers and directions of work, and develop new/adapted inquiry procedures and group structures based on emergent needs in the service of productive idea advancement (Bereiter, 2002; Gloor, 2006; Sternberg, 2003; Zhang et al., 2009).

Correspondingly, knowledge-creating organizations need organic and flexible structures that encourage participatory control and opportunistic collaboration (Engeström, 2008; Sawyer, 2007; Williams & Yang, 1999; Zhang et al., 2009). Instead of following preset "ideal" sequences of activities, members make creative decisions on what problems to tackle in an area (Sternberg, 2003), what approaches and frameworks seem promising, what specific actions and ideas are most helpful in a given time, and whom to work with for complementary collaboration.

As noted previously, current efforts to carry out inquiry-based learning in classrooms tend to design inquiry as a set of routine procedures to address predefined tasks and challenges. This routine-based notion of practices tends to underestimate the role of participants' agency and future-oriented imagination that drive dynamic changes of social practices (Miettinen & Virkkunen, 2005). Knowledge Building pedagogy adopts an idea-centered and principle-based (as opposed to procedure-based) approach to knowledge practices to support creative deep work and dynamic interactions. To explore how teachers work with the principle-based approach to enact, sustain, and improve knowledge building practices, Zhang and colleagues (2011) analyzed the principle-based knowledge building work at an elementary school across different grade levels over eight years. The results showed the continual improvement of the teachers' classroom practices, leading to increasingly productive knowledge building processes among students. As a key to the principle-based knowledge practices, the teachers worked with their students to engage in "collaborative improvisation" (Sawyer, 2004) in which the outcome cannot be fully predicted or specified in advance, and the process is co-structured and restructured by the participants instead of a single, authoritative member. With such classroom dynamics comes a high-level symmetry in teacher-student interactions, with all members of the community contributing to the flow of the classroom work and conversations (Tabak & Baumgartner, 2004).

Implementing this principle-based approach to knowledge building in broad classrooms to transform education is very challenging. In particular, the principle-based approach must contend with a widely held belief that instructional planning must specify what needs to be learned and a sequence of activities to achieve the learning goals (Scardamalia & Bereiter, 2014). Although research has shown that productive knowledge building communities—often facilitated by veteran teachers under supportive school conditions—are able to work with the improvisational process to chart the unfolding flow of sustained inquiry (e.g. Zhang et al., 2007), their success is often a “mystery” to other teachers, who have strived to adopt knowledge building but do not know how to get started. A core practical challenge arises concerning how the fluid, open, and interactively-driven processes of inquiry can be socially organized and pedagogically supported to address curriculum goals and other contextual constraints. Underlying this practical challenge is a conceptual gap about how agency-driven interactive actions and diverse ideas from students may form into a coherent and productive system of knowledge practices and be sustained over time. After all, inquiry-based learning needs to be scaffolded and supported to be effective (Hmelo-Silver et al., 2007; Lazonder & Harmsen, 2016). Otherwise, the process would run into unproductive chaos and students could easily get lost and frustrated. Our research on co-constructed structures of knowledge practices suggests a promising angle for understanding this challenging issue.

Conceptual Framework: Reflective Structuration of Knowledge Practices

We have been developing a reflective structuration perspective as a framework to understand and support collaborative knowledge practices driven by students’ distributed interactions. In a nutshell, reflective structuration of knowledge practices refers to the reflective processes by which members in a knowledge building community co-construct, use, and adapt collective structures of inquiry to channel their personal and integrative efforts into a coherent adaptive system of knowledge practices. Leveraging their ongoing knowledge building actions and discourse to advance *collective knowledge*, members in a community co-construct adaptive *collective structures*, which are shared interpretative frames about what they need to investigate as a whole community and how the community operates. Such structures serve as a social epistemic mechanism to inform individual and collaborative actions and guide ongoing reflection on progress. The reflective structuration perspective has grown out of our research on how productive knowledge building communities operate, drawing upon the related theories in the learning sciences and other fields.

To understand how knowledge practices are possibly sustained and supported in knowledge building communities that work with opportunistic and interactive processes of inquiry, we conducted a detailed analysis of the knowledge practices of a Grade 4 community facilitated by a veteran teacher (Zhang, 2013; Zhang & Messina, 2010). A prior study examined the changes made by this teacher over three years to facilitate knowledge building about light. The classroom arrangements evolved from fixed specialized groups to interacting groups and eventually to opportunistic collaboration in which students grouped and regrouped around emergent goals to advance collective knowledge. The opportunistic collaboration design led to collectively engaged knowledge building processes and productive understandings of deep scientific issues (Zhang et al., 2009). Detailed analysis of the classroom practices revealed a key strategy used by the teacher to scaffold the collaborative practices: He focused his role on leveraging communal mechanisms that made the knowledge building processes largely self-sustaining. The mechanisms involved self-sustaining loops at two levels: At the level of idea-focused work and interactions for continual idea improvement, members used/recycled their historically accumulated ideas to support their current work and generate deeper ideas and problems for further inquiry, thus, "the more we know, the more we need to know." At a meta-level of process control and organization, students engaged in reflective conversations about what research should be done and how they should best pursue their research and discourse. This led to an evolving set of co-constructed structures to guide and support the inquiry and interactions. Students generated individual, interest-driven questions, and then co-reviewed their questions to generate a shared "mission statement," which was to understand how light works. As the knowledge building work proceeded, the community further reviewed their online discourse to identify major directions of inquiry (e.g. reflection and absorption, colors and rainbow) and created new discourse spaces with labels based on the identified directions for inquiry. The mission statement and theme-based directions in the online space were used by students to guide their participation, discourse, and reflection on knowledge progress. With such co-constructed structures, students did not rely on their teacher to guide them through the whole process.

We conceptualize on the co-constructed structures of knowledge practices in light of the related work in the learning sciences and theories of social practices developed in other fields. Within the learning sciences, the situated activity theory of learning highlights social activity structures underlying learning (Greeno, 2006; Greeno & Engeström, 2014). Correspondingly, designing social activity structures is an important element of learning environment designs to support collaborative learning and inquiry (Bielaczyc, 2006; Kolodner, 2006; Linn, 2006). While most researchers treat social activity structures as something to be designed by the teacher or other learning designers, Engeström's (1987) theory of expansive learning attends to how activity structures can be expanded and transformed by learners through "double-loop learning."

Beyond single-loop learning in which participants only carry out the ongoing learning activities, learners in double-loop learning additionally build transformed understanding of fundamental aspects of the activity system, such as the goals, roles, and uses of resources, leading to a radical expansion of the scope and impact of activity (Greeno & Engeström, 2014).

While the above works are relevant, learning scientists are only beginning to understand co-constructed structures of learning practices. Deeper conceptualizations are needed to explain how co-constructed structures work to constitute and reconstitute creative knowledge practices. In this regard, we incorporate insights from the theories of social practices developed in sociology and organizational science. These theories, as a whole, explain how social practices are produced, sustained, and transformed through agency-driven structuration, offering a dynamic view of social organizing (Archer, 1982, 2003; Giddens, 1984; Knorr Cetina, 2001; Poole & DeSanctis, 1992; Schatzki, 2002; Sewell, 1992). From these theories, we identify the following conceptual elements as essential to understanding how knowledge practices are sustained and transformed.

Social Structures

A social practice becomes organized and sustains over time in a continual manner because of social structures, which are created and adapted through participants' actions and interactions. Hence, Giddens (1984) uses the term "structuration" to emphasize that structures are systems of ongoing action, being continuously produced and reproduced over time. A social practice (e.g. trading) unfolds as a flow of actions and interactions; social structures (e.g. market systems and rules) represent the more or less visible patterns or "logic" enacted in the practice. Building on Giddens, Sewell (1992) defines social structures as "sets of mutually sustaining schemas and resources that empower and constrain social action and that tend to be reproduced by that social action" (p. 19). Such social structures are both an outcome and medium of reflexive social practices, being continually produced/modified and used to guide the ongoing actions and interactions (Giddens, 1984). Social structures emerge from the ongoing actions and interactions as system-level properties, which have their own social existence and cannot be reduced to interactions of individual actors (Archer, 1982; Sawyer, 2002). Social structures exist at different social levels, ranging from local groups to larger institutions. While structures from the larger institutional context influence local structures, local structures produced and sustained through members' intersubjective understandings and coordinated actions in a group may ultimately generalize into the larger institution (Poole & DeSanctis, 1992).

The Dynamic Interplay between Structures and Agency-Driven Actions

A key to understanding how social practices are produced and transformed lies in the relationship between human agency and social structures. Despite their variations and disagreements, the social practice theories we draw upon share a dialectic approach to this relationship: These theorists attempt to avoid the extreme of voluntarism resulted from an overemphasis on human agency and choices as well as that of determinism that overemphasizes the self-propelling and self-maintaining power of social structures depressing the agency and creativity of individuals. Human agency and social structures presuppose each other: structures shape people's practices, but it is also people's agency-drive practices that constitute, reproduce, and transform structures (Sewell, 1992). Hence, social structures do not simply constrain but enable human agency. Actors appropriate existing structures historically formed in their institutional contexts, use the structures to plan and guide their ongoing actions, and reflexively monitor what is going on in individual and collective actions (Giddens, 1984). The actors' agency is reflected in their capability to reinterpret, modify, reorganize, and recreate the structures, influencing future practices by themselves and by other actors (Sewell, 1992). The temporal interplay between structure and agency is elaborated by Archer (1995) as morphogenetic cycles, which are composed of (a) a *given/existing structure* emerged from past interactions, which conditions but does not determine (b*) social interactions*, and in turn lead to (c) *structural elaboration or modification,* as intended or unintended consequences, to elaborate and modify existing structures and create new ones. The new/modified structures become part of the contexts for further rounds of agency-driven actions and structural transformation. Through this process, the social order of an activity system is maintained over time and yet can change and adapt over time as actors modify/create structures in the course of their interactions (Sewell, 1992).

Reflexive Monitoring and Deliberation

Social structures have the potential to enable and constrain certain social interactions. This potential is realized and mediated through actors' reflexive monitoring and deliberation (Archer, 2003; Giddens, 1984). Actors who carry their own interests and concerns engage in "internal conversation" to interpret and deliberate upon the social circumstances that they confront. The constraints and affordances of the social structures are thereby activated in relation to the actors' own interests and concerns. Based on the constructed relation between the actors' concerns and the social circumstances, the actors determine the courses of action to achieve what they want to achieve in society and reflect on their actions over time for possible adjustment. The reflexive monitoring and deliberation extends beyond individual reflection (internal conversation) to include interpersonal reflective conversations about their circumstances, concerns, and decisions about the courses of action (Archer, 2003). Such conversations correspond to a form of high-order discourse in the knowledge building literature: metadiscourse about the ongoing discourse to monitor collective progress and plan for deeper efforts. Metadiscourse is considered an important indicator of student agency and collective responsibility in knowledge building communities (Scardamalia, 2002; van Aalst, 2009; Zhang et al., 2009).

Structuring "Epistemic Objects" for Knowledge Practices

The above conceptual principles about social practices are applicable and essential to explaining how creative knowledge practices are enacted, sustained, and transformed. Meanwhile, the structuration of creative knowledge practices involves a relatively unique aspect: The objects of the practices are largely open-ended and need to be structured on an ongoing basis. As noted above, epistemic objects lack "completeness of being" and have the capacity to unfold indefinitely. They are progressively defined and "continually 'explode' and 'mutate' into something else" (Knorr Cetina, 2001, p. 182). They provide "unfolding structures of absences," or "structures of wanting" (Knorr Cetina, 2001, p. 182), signifying the insufficiencies of knowledge as possible foci of unfolding strands of knowledge practices. "In other words they suggest which way to look further, through the insufficiencies they display. In that sense, one could say that objects of knowledge structure desire, and provide for the continuation and unfolding of object-oriented practice" (Knorr Cetina, 2001, p. 185).

This open and unfolding nature of epistemic objects was compelling in the aforementioned Grade 4 light study. Students defined light as the overarching epistemic object, the investigation of which led to the emergence of a range of related epistemic objects: shadows, rainbows, lenses, and so forth. Each epistemic object became the focus of an unfolding strand of inquiry, with deeper knowledge gaps (e.g. why are the colors in rainbows always in the same order?) identified as progress was made (Zhang et al., 2007). Later studies of knowledge building communities in other school settings revealed similar structures of knowledge practices emerged from the classroom interactions (Tao et al., 2015, 2016, 2017; Zhang, Wilde, & Lee, 2012). The co-constructed structures were reified using various representations and resources, such as co-creating an evolving list of overarching questions, or a map of objects of inquiry to highlight what the community needed to research. Students used the structures as referential frameworks to monitor their progress and plan for personal and joint efforts to advance their knowledge (Zhang, 2013).

Our reflective structuration framework integrates the above theoretical points to understand how student-driven interactive actions and ideas in a community may form into a coherent and productive system of knowledge practices and be sustained over time. Essentially, the knowledge practices of community are dynamically organized, sustained and transformed through the dual-level (double-loop) construction driven by student agency: As members engage in interactive processes of inquiry to contribute content-specific questions and ideas and build collective knowledge, they co-construct and adapt collective structures of knowledge practices to guide and support their collaboration and contribution. The co-constructed structures provide shared expansive frames of the community's knowledge practices including the nature of the work and how the work should be organized and carried out. As the foci of the community's unfolding strands of inquiry practices, members co-structure shared epistemic objects that signify unfolding absences of knowledge, informing directions for members' personal and collaborative efforts. Hence, research on collaborative learning and knowledge building needs to identify the array of structures formed in knowledge building communities to constitute the social system of knowledge practices; examine how these structures are appropriated, co-constructed, represented, used, and adapted; and capture the relationships between the various structures (how one structure supports or conflicts with another) and their dynamic interactions with the knowledge building processes (e.g. actions and interactions). Designs of collaborative online environments to support knowledge building need to incorporate supports for students to construct collective structures of inquiry and make such structures visible for ongoing reflection and adjustment.

The Design of Idea Thread Mapper

Existing designs of collaborative learning environments focus on scaffolding specific inquiry actions and discourse moves, such as questioning and evidence-based arguments (e.g. Kollar et al., 2006). Students post ideas in online discourse to address teacher-specified topics and tasks; rarely do they have the opportunity to structure and restructure their collaborative practices. As another related challenge, in online discourse environments in the forms of online forums and chatting, student ideas are recorded in individual online posts distributed over time. It is difficult for students to see the collective landscape and structures (e.g. directions and strands of inquiry) emerge from the distributed discourse and interactions (Hewitt, 2001; Suthers, Vatrapu, Medina, Joseph, & Dwyer, 2008). Without clear awareness of their community's goals, directions, and progress, students' discourse entries are often ill-grounded and disconnected, lacking progressive deepening moves (Zhang, 2009). Therefore, further advancements of collaborative learning environments need to provide opportunities and supports for students to co-construct collective structures of knowledge practices, as a community, and make the structures visible to students to support their reflective monitoring and planning.

To address the above needs, we designed a timeline-based, collaborative structuration tool for sustained knowledge building: Idea Thread Mapper (ITM) (Chen et al., 2013). In line with the reflective structuration framework, ITM is designed to support student co-construction of collective structures as they engage in ongoing knowledge building discourse, and to further make the structures visible to students to guide their participation, collaboration, and reflection.

Core features of ITM focus on building and mapping out unfolding strands of knowledge practices to address emergent epistemic objects as the focus of the community's work. The structures signify high-level properties of the knowledge practices based on student online discourse in connection with their face-to-face work, including: (a) shared epistemic objects being investigated and absences of knowledge to be addressed by the community; (b) unfolding, interrelated strands of inquiry practices focusing on the epistemic objects to generate deepening ideas; and (c) members' collaborative roles in the different strands of inquiry and discourse.

Specifically, ITM interoperates with Knowledge Forum (Scardamalia & Bereiter, 2014) and potentially other platforms for collaborative discourse. In these online environments, students contribute and build on one another's ideas in interactive discourse, with ideas presented in distributed postings (e.g. notes) and build-on responses. Beyond these micro-level representations of ideas as postings and build-on notes, we introduced "idea threads" or "inquiry threads" as a larger structure unit. Each idea thread is defined as a sequence of discourse entries (possibly involving several build-on trees) that investigate a shared epistemic object (e.g. batteries), as an unfolding strand of inquiry (Zhang et al., 2007). Each object is the focus of an extended line of inquiry involving a number of contributors. To support student efforts to frame unfolding desires and needs of knowledge related to each epistemic object, ITM includes a feature for students to frame the deepening inquiry directions in each idea thread by co-authoring a "Journey of Thinking" synthesis. The "Journey of Thinking" synthesis includes reflections on what the community needs to understand, "big ideas" learned so far, and deeper actions needed. At a higher communal level, the collective landscape of a whole inquiry is mapped out as clusters of idea threads that investigate interrelated objects through the contributions of all the members (see Figure 1 for the map of idea threads created in a Grade 5/6 electricity study). The map of idea threads further shows cross-thread connections, including build-on links among notes from different threads and connective “bridging-contributions,” each of which simultaneously addresses two or more related epistemic objects.

Insert Figure 1 about here

Our team has conducted a set of initial studies to explore ITM-supported reflective structuration of knowledge building practices in Grades 3-6 classrooms (Chen et al, 2013; Tao et al., 2015; Zhang et al., 2013, 2014). In each knowledge building initiative that investigated a core science topic over multiple months, students carried out various inquiry activities and participated in extended knowledge building discourse on Knowledge Forum to deepen their understanding. ITM-based classroom designs focus on engaging students in reflective processes and conversations to create structural representations of their unfolding knowledge practices. Students use the structures to monitor their inquiry: to frame the major epistemic objects and organize the associated inquiry work, to review progress and knowledge absences/gaps, and to propose actions for deeper research. The results suggest that the third- to sixth-graders were able to conduct meaningful reflective conversations to review shared objects of inquiry and organize the related knowledge building discourse, although the third-graders needed more guidance and support from their teacher. Analyses of online discourse and student interviews suggest a number of potential benefits: through ITM-supported reflective structuration, students showed a clearer and broader awareness of their community’s foci and progress in the whole inquiry beyond student personal focus and interest. Their online discourse after the reflective structuration also became more connected with more interactive build-ons (Chen et al., 2013). Compared to their questions raised in regular online discourse, students also generated deeper questions in their Journey of Thinking syntheses, seeking explanations of underlying mechanisms beyond basic facts (Zhang et al., 2013, 2014).

The Purpose of This Research

Building on the findings from the initial studies, the current research aims to further explore the design of ITM-supported reflective structuration and examine its impact on student knowledge building. In the above initial studies, ITM-supported reflective adaptive structuration was implemented as a single session during each knowledge building initiative. The full process and potential of reflective adaptive structuration need to be examined as an ongoing process. In the current research, ITM-supported reflective structuration was implemented as two intensive sessions with ongoing individual and collaborative reflection across the whole knowledge building process. To examine the impact of reflective structuration more systematically, the current research included a comparison classroom and conducted more detailed analysis of student online discourse and learning outcomes.

Our research questions ask: (a) How do students co-construct collective structures to frame epistemic objects as the foci of the unfolding strands of knowledge practices, with what support from their teacher? (b) To what extent does ITM-supported reflective structuration contribute to improving the community's knowledge building discourse and enhancing the scope and depth of student understanding?

Through investigating the first question, we expect to produce a detailed account of the reflective processes and conversations by which the community co-constructs, adapts, and uses the collective structures in knowledge building. Following the suggestions from Poole and

DeSanctis (2004) on how to analyze the structuration processes in group interactions, our analysis will identify and trace the relevant structures in the knowledge building community that operates as a social system embedded in the school's context. The analysis will capture the reflective processes and conversations enacted by the agents/actors to appropriate, produce, use, and modify the structures, focused on framing the epistemic objects and related unfolding strands of inquiry.

As the assumptions guiding our analysis of the second question, we expect that by engaging in ITM-supported reflective structuration that brings forth collective structures of knowledge building, students should be able to make more purposeful and coherent contributions while investigating the epistemic objects of their community. As the indicators of such enhanced efforts, students will engage in more active and richly connected discourse to address deep questions. As a result, students with ITM-supported reflective structuration will develop deeper and more coherent understandings in their domain area of inquiry.

Method

Research Participants and Classroom Contexts

This study was carried out in two Grade 5/6 classrooms at the Dr. Eric Jackman Institute of Child Study in Toronto, a K-6 laboratory school that had been implementing Knowledge Building pedagogy over a decade. There were 21 students in classroom A and 22 in classroom B participating in this research, who were 10 to 12 years old. The two classes were taught by two experienced teachers, respectively, each having multiple years of experience with facilitating knowledge building and inquiry-based learning. The students in both classrooms were acquainted with the classroom processes of knowledge building, which had been implemented across grade levels at their school. Students in each classroom investigated electricity over a 12-week period, with two science lessons each week. Their work integrated a wide range of activities including student-directed experiments and observations, whole class knowledge building conversations, individual and cooperative reading, and so forth. Major ideas, questions, and findings generated through face-to-face activities were contributed to Knowledge Forum for continual knowledge building discourse online. The whole knowledge building initiative unfolded as a continuous process without pre-specified topics and sequences of activities.

Research Design

As an exploratory, mixed-methods study (Creswell & Plano Clark, 2011), this research integrated quantitative and qualitative data analyses that complemented and cross-validated each other in addressing the two research questions. The first question (about the processes of reflective structuration) implemented in classroom A was addressed through qualitative analysis of classroom videos, observation notes, and teacher meeting records. The second question (about the impact of reflective structuration on knowledge building) was investigated using quantitative analyses that involved a between-condition comparison. For the purpose of comparison, only classroom A implemented reflective structuration as an intentional, systematic, and ongoing effort. Specifically, students in classroom A had two ITM-supported reflective sessions, first in Week 4 and then in Week 8 of the 12-week electricity inquiry. Throughout the inquiry, students were encouraged to monitor inquiry topics and problems that emerged from their community's work and make intentional contributions addressing the community's needs. Classroom B did not use ITM until Week 9, when students conducted a single reflection session to review their online discourse. Our data analysis focused on the first eight weeks of work in the two classrooms: Classroom A represented the experimental condition of knowledge building with ITM-supported reflective structuration, and classroom B represented a comparison group. Therefore, comparing the knowledge building processes (e.g. discourse) and outcomes between the two classrooms during this time period allowed us to gauge the impact of reflective structuration with ITM.

Classroom Processes

In Week 1-3, both classrooms began their electricity inquiry with hands-on explorations of static electricity, circuits and conductors, and magnets. Students discussed their initial findings in small groups and further shared their questions and ideas about electricity through a whole class conversation. Focusing on their questions, students conducted research using books, online materials, videos, and experimental kits. Extending their face-to-face interactions, students wrote and built on one another's notes in Knowledge Forum to discuss their ideas, observations, and questions.

In Week 4, classroom A conducted its first ITM reflection session, which included the following components:

(a) Individual reflection on emergent topics and questions of inquiry in the knowledge building discourse;

(b) Whole class reflective conversation to review and identify focal epistemic objects emerged from the ongoing knowledge building discourse and create a collective list of "juicy topics," as the shared focus and directions of research;

(c) Small groups' reflective work to organize the online discourse contributions related to each epistemic object, as an idea thread;

(d) Whole class reflective conversation to examine the map of all the idea threads (see the idea threads in Figure 1 before the first ITM session) and review collective advances, cross-thread connections, and directions of further inquiry; and

(e) Defining absences of knowledge and deeper actions of research needed in each area by writing a “Journey of Thinking” for each idea thread, using a set of scaffolds to highlight the problems of understanding, “big ideas” learned, and deeper actions needed.

To address the deep themes and problems identified, students conducted further inquiry in the subsequent three weeks. New notes were added to Knowledge Forum for extended online knowledge building discourse. In Week 8, classroom A conducted its second ITM reflection session, in which students revisited the map of idea threads generated earlier and updated each idea thread by including new Knowledge Forum notes addressing deeper issues. More detailed processes of ITM-aided reflection in Classroom A are presented in the Results section.

During the above time period (Week 3-8), classroom B continued its knowledge building without ITM-supported reflection. Students posted questions in Knowledge Forum and shared questions using Post-It notes. They then conducted research focusing on their questions using books, videos, and online materials; created models (e.g. electroscope); and shared their findings in classroom discussions. Supporting their reflection and sharing of knowledge, students worked in groups to create posters focusing on their specific topics of research (e.g. batteries, conductors). In this process, students shared their work on Knowledge Forum and responded to one another’s ideas and questions. Week 9, classroom B implemented its only ITM-aided reflection session following the processes used by classroom A in its first ITM reflection session.

In the rest of the inquiry (Week 9-12), students in both classrooms concentrated on classroom-based inquiry to understand the deep issues identified and preparing culminating artifacts (e.g. presentations) to share their new knowledge as a whole class.

Data Sources and Analyses

Analyses of classroom observation notes and video of reflective structuration in the context of the knowledge building processes. To address the question of how students co-constructed collective structures to frame epistemic objects as the foci of the unfolding strands of knowledge practices, we conducted qualitative analyses of the classroom observation notes and video records of the ITM reflection sessions. This analysis was further supported by our notes from the monthly teacher meetings, organized to plan and reflect on the classroom inquiry. A research assistant observed each science lesson in the two classrooms and took detailed notes about the classroom processes. ITM-supported reflection sessions and other major classroom activities (e.g. whole class discussions) were video-recorded. The classroom videos were fully transcribed and analyzed using a narrative approach to video analysis (Derry et al., 2010). The construction of the narrative based on the videos and other data focused on capturing the reflective *processes* enacted by the *actors* (students and teacher) to appropriate, produce, use, and modify various *collective structures* to frame the epistemic objects and unfolding strands of inquiry. Two researchers first browsed the videos and transcriptions to develop an overall sense of the reflective processes, and then identified “digestible” chunks in the videos—major episodes of the reflective conversations by which students identified and negotiated high-potential “juicy topics” of inquiry, organized unfolding strands of inquiry and discourse, documented knowledge progress and gaps, and planned for deeper inquiries. These chunks of videos were analyzed to capture who (the actors) enacted what kinds of reflective processes to develop what sorts of structures and related artifacts or resources (cf. Poole & DeSanctis, 2004). The video episodes were further contextualized through building chronological links among the episodes and with our observation notes to construct a storyline.

Analysis of the online knowledge building discourse. To examine the impact of ITM-supported reflective structuration on the community's ongoing knowledge practices, we analyzed student contributions and interactions in their online knowledge building discourse. The online discourse was a major component of the knowledge building processes and further provided a screen onto which the classroom work was projected. Specifically, we conducted both quantitative and qualitative analysis of student online discourse over the first eight weeks and compared the interaction patterns between classroom A and B. Two researchers first read the notes of each classroom in a chronological sequence to develop an overall sense of the online discourse in relation to the ITM reflection captured in the classroom videos. For quantitative analysis, we used the analytic toolkit underlying Knowledge Forum to generate statistics of note contributions and build-on connections. Deeper content analysis (Chi, 1997) was conducted to code specific discourse moves by which students contributed to their community's knowledge. Drawing upon prior studies of productive patterns of knowledge building discourse (Chuy et al., 2011; Zhang & Sun, 2011), we designed a coding scheme that included four categories of contributions: questioning, explaining/theorizing, using evidence, and integrating and applying ideas (see Table 1). Questions were further coded based on fact-seeking vs. explanation seeking; and initial wondering vs. idea-deepening questions. This coding scheme was tested by two coders, who independently coded 175 notes to assess inter-rater reliability, resulting in an agreement rate of 94.7% (Cohen's Kappa = 0.94). Following the coding procedures tested, a primary coder coded each of the Knowledge Forum notes from the two classrooms.

Insert Table 1 about here

Content analysis of students' individual summaries of what they had learned. To assess student understanding of the various electricity-related topics investigated by their community, we asked each individual student in classroom A and B to orally summarize what he/she had learned. The students first responded to a prompt question asked by the researcher: "What are the important things you have learned about electricity?" They then elaborated their understandings of each of the topics mentioned, with the opportunity to go beyond their initial list of topics. Each student's summary was audio-recorded, transcribed, and coded through content analysis (Chi, 1997). Specifically, two researchers first read the online discourse and observation notes of the two classrooms to identify various topics of inquiry mentioned in relation to the topics specified in the curriculum guidelines. They shared the identified topics and merged similar or closely related topics (e.g. atoms and electrons), with a final list of 10 topical categories created (e.g. batteries, static electricity, voltage and charge, atoms). A primary coder then read each student's summary to identify utterances related to each of the topics. The ideas related to each topic were further coded based on epistemic complexity and scientific sophistication using coding schemes tested through our previous studies (see detailed coding frameworks and inter-rater reliability reported in Tao et al., 2015, 2016; Zhang et al., 2007, 2009). Scientific sophistication examines the extent to which students' ideas align with a scientific framework of electricity based on a four-point scale: 1 - pre-scientific, 2 - hybrid, 3 - basically scientific, and 4 - scientific. Epistemic complexity indicates students' efforts to produce not only descriptions of the material world, but also theoretical explanations and articulation of hidden mechanisms, which are central to the pursuit of science (Salmon, 1984). Focusing on epistemic complexity, a five-point scale (1- topic term only, 2 - unelaborated facts, 3 - elaborated facts, 4 - unelaborated explanations, and 5 - elaborated explanations) was used to code ideas about each topic.

Beyond assessing student understanding of each individual topic, we analyzed the level of coherence in explanations about different topics that focused on the nature of electricity. Borges and Horizonte (1999) identified increasingly complicated mental models used by students to explain how electricity works. These range from a general conception of electricity as the flow of energy to a more informed focus on positive and negative charges, a deeper explanation of the charges based on the movement of electrically charged particles, and the most complicated understanding of electricity as a field phenomenon. Deeper conceptualizations favor more coherent understanding of seemingly different phenomena that share the same fundamental mechanisms. In light of these mental models of electricity, we created a coding scheme (Table 2) to categorize each student's explanations across the topics, such as electric circuits, conductors, batteries, current, and charges. Table 2 does not include electricity as a field phenomenon (category 4) because none of the students in this study showed this understanding that is far beyond the level of Grade 5/6. Two raters independently coded 21 portfolio summaries using this coding scheme, resulting in an inter-rater agreement of 95.24% (Cohen's Kappa = 0.97).

Insert Table 2 about here

Results

How Did the Students Co-Construct Collective Structures to Frame the Epistemic Objects as the Foci of the Unfolding Strands of Knowledge Practices?

Through narrative analysis of the classroom videos supported by our classroom observations and notes from the teacher meetings, we identified salient reflective processes by which classroom A co-constructed shared framing of epistemic objects to structure and guide its knowledge building work. These processes are summarized in Table 3 and elaborated below.

Insert Table 3 about here

(a) Introducing electricity as the overarching area of inquiry. The science curriculum of Ontario for Grade 5 and 6 includes electricity and several other scientific topics. At their planning meeting, the teachers considered these topics based on conceptual richness as well as the school's typical teaching schedule developed in the past few years. Based on these factors, they selected electricity as the topic of inquiry for the first part of the school year. In the first week of this inquiry, the teachers introduced electricity as the overarching area of inquiry. However, they did not specify what specific topics and questions their students should work on, but encouraged students to define the inquiry directions based on their interests and questions. "Electricity study" became the name used to refer to this inquiry work. An "Electricity" view was created in Knowledge Forum for each classroom as the online discourse space for this inquiry.

(b) Individual noticing of potential epistemic objects in inquiry activities. Students engaged in a hands-on exploratory activity planned by the teacher. Students worked independently and in small groups to experiment with a range of materials including: batteries, wires, light bulbs, magnets and iron filings, balloons, and different types of fabric to explore static electricity. Questions were generated by the students based on their observations, such as: Why is hair attracted to the balloon after rubbing it against your hair? How is static electricity similar to regular electricity? Students took notes of their questions and ideas in their science notebooks. They conducted research about their questions in the following week using books, websites, and experimental materials, and they posted their ideas and questions in Knowledge Forum. As reflected in their individual notebooks and online posts, students captured interesting issues to be investigated as they interacted with the electrical devices and phenomena in the hands-on exploration, encountered various scientific concepts (e.g. charge) in readings, and shared questions among their peers. The individual noticing and monitoring of potential inquiry objects as they arose from the community's ongoing work and discourse formed the foundation for coherent collective structures to emerge. In this process, the teacher did not predefine the objects of inquiry. Instead, he played out his influence by bringing certain experimental materials to the classroom, suggesting books and other readings to students, and participating in the classroom discussions to share interests in and ideas about certain topics.

(c) Framing and structuring knowledge building discourse around "juicy" epistemic objects. By the end of the third week, students in classroom A had created 89 notes in their Knowledge Forum view. In Week 4, the whole class conducted a reflective conversation to co-review what was going on in their collective discourse. Different from regular classroom conversations focusing on developing ideas to address specific questions, the reflective conversation was focused on reviewing and organizing the community's collective work. With their Knowledge Forum view projected on a Smartboard, the teacher first contextualized the conversation by saying:

> *"We had some time to both work with materials and experiments and stuff, and work in the Knowledge Forum view. ... So, I had a look at it [Knowledge Forum view] over the last little while and found that it's enormous, and very, very complicated… What I was thinking we could do … is to look at it and see what the major threads of ideas are. ... Can somebody notice? ... What's one big kind of "juicy" topic that's being talked about in the view?"*

The teacher shared his further reflection on what topics may be considered as "juicy": *"I don't mean just big [points to big build-on tree in the view] like there are a lot of notes, but they might be important, juicy topics."* Students responded to propose various topics discussed. They first identified very specific topics, such as notes mentioning "lemon juice" in their titles. The teacher encouraged students to further frame the conceptual focus related to electricity, by asking: "What are these notes about?" Students reframed their posts about their experiments with lemon juice as how batteries work, and as a potential "juicy topic" of inquiry. Continuing the reflection modeled as a whole class, each student then worked with a partner to conduct more careful review of potentially "juicy topics" addressed in the online discourse. Each group was given a printout of the Knowledge Forum notes, discussed what had been investigated, and circled clusters of notes discussing different topics using color markers. The whole class then reconvened to share the topics identified, with the teacher recording the topics on a board. A total of 10 topics were recorded, including batteries, static electricity, magnets, voltage and charge, energy sources, Leyden jar, atoms, electrons, positive/negative, and light. The teacher facilitated further reflective talks among students to clarify the deeper electrical processes and objects under some of the specific topics.

> Teacher (T): Okay, this is a pretty good list. Are there any of these…that probably just fit exactly together and we probably don't need two different categories for?
>
> S1: Positive/negative and electrons.
>
> T: Positive/negative and electrons. OK. [draws an arrowed line between these two topics on the board] Any other ideas…?
>
> …
>
> S2: Leyden jar and static electricity.
>
> S3: Yeah.
>
> T: Leyden jar and static electricity. Might be part of the same thing? [draws an arrowed line between these two topics on the board] Like that? Did some people put Leyden jar under static electricity?
>
> Several students talk together: Yeah.
>
> T: OK. …So we have eight main threads.

Based on the eight "juicy" epistemic objects identified, students used ITM to organize and review their online discourse related to each object as an idea thread. The teacher explained the purpose of ITM and went through an initial pass with the whole class to co-construct one idea thread, as an example. Eight voluntary small-groups were then formed to construct idea threads for the eight topics of inquiry, with one of the groups working on the example idea thread started by the teacher. Focusing on each focal topic, group members first discussed what key terms should be used to search for Knowledge Forum notes related to their topic. They reviewed the notes and selected those that contributed important understandings. ITM displayed the selected notes on a timeline as an idea thread and further retrieved authors involved in this line of work, with options to show build-on connections over time (see Figure 2).

Insert Figure 2 about here

(d) Using idea threads as a structure to monitor collective progress and deliberate deepening goals and inquiry activities. To reflect on the knowledge practice and progress of the whole community, the teacher mapped out the eight idea threads on the same timeline (see notes before the first ITM session in Figure 1) and facilitated a reflective conversation about the inquiry progress and directions.

> Teacher (T): …we can see the map [points to the map of the eight idea threads on the screen] of all the things we're thinking about. So take a look and tell me what you notice…So the lines that have gone all the way through are the ones that we've been talking about all of the time. The ones that started and stopped are ones that we've been doing for some smaller portion of time. It also tells you the amount of notes there are. There are 33 notes related to voltage and charge in some way, which is kind of interesting. S1, what do you notice?
>
> S1: That atoms didn't really start to come up because N (an invited speaker) did that lesson about positive and negative and to help us find out about batteries, and then …you (the teacher) started to talk about atoms so it wasn't at the beginning.
>
> T: Yeah,… this [note] about atoms came up later. What's one that someone else

noticed, either about the number of notes or which ones have been going for a long time…

S2: Static electricity has been going on for the longest time…but it has one of the least notes.

T: Yeah, it doesn't have a ton of notes in it, right? Static electricity. S3, what do you notice?

S3: Some of the magnets… first of all, there were not that many notes and a lot of them were bad, like notes for no reason…

T: Oh, I see…now you have like a bunch of different threads with a bunch of different ideas that you can work on, what do you think would be a really good use of your time? So if you said, OK, I've got to work on one of these, what would you work on?

S4: The one with the least amount of notes…Either light…or magnets.

In the above excerpt, members reflected on how the different idea thread topics emerged and reviewed the intensity, quality, and timespan of the contributions in each idea thread. They pointed out threads that had few notes or needed more solid contributions, and proposed further actions for deeper work in these areas in the coming weeks. Threads with very few authors were also evident in the map view of idea threads, informing potential opportunities for students to expand their participation and connections with their peers to make needed advances.

In the next two weeks, students volunteered to do deeper research in the needed areas that were most related to their personal interests. Students working on each thread topic authored a group Journey of Thinking synthesis to summarize the "big ideas' learned, focal problems to be further addressed, and specific actions to be taken. For example, reviewing progress in the idea thread about magnets that included eight notes by 10 authors by the time of the ITM reflection, two students co-created the Journey of Thinking synthesis shown in Table 4, highlighting "big ideas" learned as well as core problems to be addressed through further actions of inquiry. The Journey of Thinking syntheses written for the different threads were transferred to a big chart paper, which was hung on a wall in the classroom to highlight the "big ideas" and problems to the awareness of the whole class.

Insert Table 4 about here

(e) Re-framing and reorganizing the idea threads based on new practices and progress. To address the weak areas and deep problems related to the major epistemic objects, students conducted individual and collaborative research using a set of books, videos, websites, and experiment materials. They shared their new ideas and questions in their face-to-face and online discourse. For example, in a whole-class discussion, students shared their summaries of the "big ideas" learned about each theme. Reflecting on the ideas shared, students revisited the eight "juicy" epistemic objects and their connections to organize what their community was working on.

> S1: Magnets go to electrons and...static [electricity] makes voltage and charge, and that makes energy. When you rub it, the fur is charging up the rod and it's all "electron-y" and that means the fur is positive. When we create an electrical charge by putting electrons on something, or taking electrons away from

something, we get static electricity.

…

S2: I think that maybe everything is related to each other. Once we learn more, we might see how all these threads relate to each other.

S3: When you put your finger on Leyden jar (when studying static electricity), it sparks. A huge number of electrons rush to your finger. If you took a whole lot of electrons together, all pressed together, they look like the spark…

S4: Everything is connected, so they are all the same thing: electrons are part of atoms and electrons have charge, and so charge is connected to atoms through electrons.... All are connected... Chain ends at atoms every time because atoms are everything and everything is made up of atoms. It is the essence…It all comes back to atoms and understanding how atoms work.

The teacher participated in this discussion by asking for more detailed thoughts about the nature of the connections and taking visual notes on a Smart Board to keep track of the connections identified. Figure 3 shows the visual created. Instead of a simple list of eight inquiry topics, the community reframed the focus of the knowledge building work as an interconnected web of epistemic objects to be understood as a whole, suggesting opportunities for conceptual and social connections.

Insert Figure 3 about here

This insight in cross-thread connections was also reflected in the Journey of Thinking syntheses authored by student groups. When synthesizing "big ideas" in each idea thread, students mentioned electron movement in six out of the eight idea threads: *"Everything is made of atoms. The atoms are made out of protons, neutrons, and electrons." "Electrons have a negative charge. It's always electrons that transfer onto your body when you rub your foot on the carpet." "Electrons moving create energy."*

In the subsequent classroom discussions, the visual of the interconnected inquiry topics was displayed on the Smartboard to focus and guide student interactions. As advances were made through their deeper research, students in classroom A continued their knowledge building discourse online. In Week 8, they conducted another ITM reflection session in which they reviewed the idea threads organized about four weeks ago and updated each thread by adding the new relevant contributions (see Figure 1 for notes added after the first ITM session). For example, the idea thread on magnets was extended from eight notes by 10 authors by the first ITM reflection to 18 notes authored by 14 students.

Students in classroom B engaged in a similar set of knowledge building activities to investigate their questions about electricity and share their questions and ideas on Knowledge Forum. Their online discourse addressed a wide range of issues, which were not systematically reviewed until Week 9 in late November. The teacher in classroom B facilitated an ITM-supported reflection session following similar processes used by classroom A in its first ITM reflection session. As the video records and classroom observation notes revealed, the teacher first contextualized the reflective conversation by showing the Knowledge Forum view with over 150 notes, highlighting the need to review what the students were researching: to reconnect the notes "with some things that you were wondering about" and with "juicy" and "big" topics. Students responded to share their thoughts about what a "juicy" and "big" topic looked like.

They then worked in small groups to review the printout of their Knowledge Forum view and color-code notes addressing various possible “juicy topics.” The topics identified were shared through a whole class reflective discussion, leading to the formulation of nine “juicy topics” as the collective focus of classroom B, including atoms, batteries, circuits, conductors, static electricity, energy, and so forth. Students further worked in small groups to select relevant Knowledge Forum notes for each topic, as an idea thread, and write a Journey of Thinking synthesis for each idea thread to highlight knowledge progress and deeper questions. However, because the idea threads and syntheses were created near the end of the electricity unit, students in classroom B only had very limited time to use these artifacts to guide and pursue deeper research.

To What Extent Did ITM-Supported Reflective Structuration Contribute to Enhancing the Knowledge Building Discourse?

To examine the impact of ITM-aided reflective structuration on student knowledge building practices, we analyzed the online knowledge building discourse of the two classrooms during the first eight weeks when only classroom A implemented reflective structuration. We first compared the online discourse of the two classrooms based on two quantitative measures: the number of notes contributed by each student and the percentage of notes with build-on links among all the notes posted. Each student contributed an average number of 8.30 notes (SD = 4.56) in classroom A and 4.60 notes (SD = 2.12) in classroom B, with a significant difference (t = 3.4379, df = 41, $p < .01$). Among the notes posted by each classroom, 37.60% of classroom A’s notes and 33.20% of classroom B’s notes had build-on links. Through reflecting on and co-constructing collective structures of knowledge building, students in classroom A made more active and connected contributions in their knowledge building discourse.

To further examine the specific discourse moves made by students, we conducted content analysis of the online discourse focusing on the nature of their questions and specific moves to address the questions. As Table 5 shows, classroom A had a higher proportion of notes raising questions than classroom B. More specifically, classroom A had a higher percentage of notes asking explanation-seeking questions (e.g. why, how) as opposed to fact-seeking questions, and idea-deepening questions in search of deeper understanding (e.g. Why does the static charge not work well at high levels of humidity?) as opposed to initial wondering questions (e.g. how does static electricity work?). In both classrooms, a majority of the notes contributed personal explanations to address the various questions. Overall, classroom A had a lower proportion of notes sharing personal explanations than classroom B; but it had a higher proportion of notes using evidence to back up their explanations and integrating ideas to solve problems and understand cross-theme connections. For example, a student in classroom A wrote: *"Electrons are the essence of charge. Atoms are the root of everything having to do with electricity."*

Insert Table 5 about here

Deepening the quantified analysis above, we qualitatively traced the online discourse moves in each idea thread in connection the community's structuration of "juicy" epistemic objects. As a compelling pattern, the foci of students' posts evolved from more concrete toward more conceptual objects to search for underlying mechanisms, which brought forth deep connections across the different threads of discourse. As noted earlier, the whole inquiry initiative began with student hands-on exploration of batteries, light bulbs, magnets, and static electricity. Students' initial online discourse focused on sharing their observations and questions, serving as the starters of the idea threads about batteries, static electricity, energy sources, and magnets (see Figure 1). Sustaining inquiry in these idea threads, students searched for conceptual explanations of the empirical facts that they had observed. More abstract concepts (e.g. electric charges, electrons, and atoms) emerged and became the objects of inquiry in their own right, leading to the emergence of the idea threads focusing on these objects. For example, students' online discourse on fabrics that cause static electricity gave rise to the concepts of negative and positive charges. Interest thus emerged among the students to positive and negative charges, electrons, and atomic structure. In the first ITM reflection session, students explicitly identified such abstract concepts as electric charges and voltage, atoms, and electrons as core topics of inquiry in their community. They further formulated deeper explanation-seeking questions about electrons and electric charges in the Journey of Thinking syntheses regarding these topics, such as: What makes electrons move? What is the connection between atoms and energy? These objects and questions of inquiry became the focus of the subsequent discourse and inquiry work. As Figure 1 shows, the idea threads about charges/voltage, atoms, and electrons involved the most intensive discourse after the first ITM reflection in mid-October.

Using the analytics embedded in ITM, we further examined how the discourse in the different idea threads of each classroom was connected through the "bridging notes," each of which simultaneously talked about multiple interrelated objects of inquiry. The bridging notes were marked using vertical dashed lines in the idea thread map shown in Figure 1. For example, on November 8, a note about lightning was created in two idea threads: Light and Voltage and Charge, explaining lightning based on positive and negative electric charges. As expected, classroom A had more extensive cross-thread connections than classroom B (see Figure 4).

Insert Figure 4 about here

To What Extent Did ITM-Supported Reflective Structuration Contribute to Enhancing Student Understanding of Electricity?

To measure student understanding achieved through the knowledge building practices, we conducted content analysis of student personal summaries of what they had learned about electricity. The coding scheme captured the number of content topics addressed, the scientific quality (from pre-scientific to scientific) of ideas related to each topic, the epistemic complexity of ideas (from unelaborated facts to elaborated explanations), and the mental models based on which students explained electricity (see Table 2).

On average, students in classroom A summarized more inquiry topics about electricity (M = 5.89, SD =1.63) than students in classroom B (M = 4.65, SD =1.18) (F (1.37) = 7.51, p = .009). Specifically, classroom A had many more students summarizing understandings of abstract topics such as electrical charges and atoms and electrons. The average scientific rating of students' ideas in both classrooms was between "3 - basically scientific" and "4 - scientific" without significant difference ($p > .05$). Students in classroom A articulated understandings of the various topics at a higher level of epistemic complexity (M = 3.94, SD = .58) than those in classroom B (M = 3.49, SD = .53) (F (1,36) = 6.51, p = .015), showing explanations of mechanisms, processes, reasons, and relationships.

Student ideas about the different topics about electricity were further coded as a whole to gauge their primary notions (mental models) about how electricity works. Figure 5 shows the proportions of students giving different explanations, with a significant difference between the two classrooms (X^2 = 16.03, *df* = 3, *p* = .001). Classroom A had higher percentages of students giving more advanced explanations conceiving electricity as negative and positive charges (category 2) carried by electrically charged particles (category 3). On the contrary, a majority of students in classroom B explained electricity at a general level based on energy flow from the battery to the light bulb (category 1).

Insert Figure 5 about here

Discussion

Based on the above-reported findings, we discuss the reflective processes by which the students co-constructed and adapted collective structures of inquiry with their teacher's support and look into the impacts of reflective structuration on student knowledge building.

Co-Constructing Collective Structures: Frame Unfolding Strands of Knowledge Practices Focusing on Epistemic Objects

In line with the social practices of authentic knowledge-creating organizations, classroom-based knowledge practices need to embrace higher levels of flexibility and interactive dynamics and encourage students to enact high-level agency for charting the courses of inquiry (Scardamalia, 2002; Zhang et al., 2011). This research elaborated reflective structuration as a mechanism to understand and support knowledge practices driven by students' distributed interactions over several months. The processes of reflective structuration were supported by ITM designed to make emergent collective structures visible in interactive knowledge building discourse, focusing on the unfolding strands of inquiry to address high-potential epistemic objects in a domain area. As Knorr Cetina (2001) points out, epistemic objects are different from material things in that they “are characteristically open, question-generating and complex” (p. 181), providing unfolding structures of knowledge absences and desires that drive continual actions of inquiry. The results of this study provided a detailed account of how the students in classroom A co-constructed structures of inquiry to frame “juicy” epistemic objects and organize their knowledge building process accordingly with their teacher’s support. The construction, adaption, and enactment of the structures went through multiple reflective cycles.

(a) Appropriation of initial, open structures. The kick-off of this inquiry was supported through the introduction and appropriation of electricity as the overarching area of inquiry. The teachers played an important mediating role in interpreting the structures afforded by their curriculum guidelines in relation to the circumstances of teaching in the current school year and the school’s past practices. The constraints and affordances of the existing structures in the school’s contexts were thereby activated in relation to the teachers’ own interests and intents. The overarching area of inquiry was introduced to the class and further reified and materialized through the creation of the “Electricity” view in Knowledge Forum as the online workspace. This initial structure signified a recognizable yet open-ended direction of research without specifying the specific topics and questions.

(b) Knowledge building actions and interactions drawing upon the initial structures. With electricity set as the overarching area of inquiry, students engaged in a range of knowledge building actions and interactions including experiments, individual and cooperative reading, whole class conversations, and online discourse. In the activities, students brought activity-specific structures to their participation, such as the use of Knowledge Forum scaffolds to highlight problems of understanding. Various potential objects of inquiry came to the students’ attention, including electricity-related phenomena (e.g. static electricity), concepts (e.g. voltage), and devices (e.g. battery). While doing initial research about these issues, students documented their ideas as well as questions, informing specific directions of research. The teachers played an important role in "seeding" the potential objects and directions of inquiry by bringing certain experimental materials and books to students and sharing personal interests in classroom discussions.

(c) Building elaborated structures to frame and organize the unfolding strands of inquiry. On the basis of individual noticing of potential objects of inquiry and related questions, students engaged in reflective conversations about what they were researching. Through the reflective conversations in small groups and, then, as a whole class, the community shared individually identified topics, reviewed their connections, and formulated a collective list of eight "juicy topics." This collective list of "juicy topics" elaborated the overarching area of electricity into a set of interrelated epistemic objects, which provided an organizing structure for the continuation and unfolding of object-oriented knowledge practice (Knorr Cetina, 2001). This structure was reified and materialized through ITM, which was used by students to organize their online discourse contributing to the research of each "juicy topic" as interconnected idea threads, showing the unfolding strands of inquiry in their community.

(d) Using the structure of idea threads (inquiry strands) to guide further actions and interactions, leading to further structural elaboration. The map of idea threads served as a guide to support students' reflexive monitoring (Archer, 2003; Giddens, 1984) of what was going on in their community and what needed to be achieved, informing intentional and connected contributions made by the community members to advance their understanding. Further structural elaboration and modification (Archer, 2003; Sewell, 1992) occurred through the documentation of the Journey of Thinking in each idea thread and the mapping of cross-thread connections. The Journey of Thinking synthesis documented progress as well as deeper needs of knowledge, highlighting "unfolding structures of absences" (Knorr Cetina, 2001, p. 182) related to each epistemic object. The map of cross-thread connections provided a coherent whole picture of the community's practice, suggesting important conceptual connections as well as opportunities for collaboration.

Overall, the multi-cycle reflective processes align with the cycles of structuration and structural elaboration highlighted by the theories of social practices (e.g. Archer, 2003; Giddens, 1984; Sewell, 1992): An appropriated/formed structure conditions (but does not determine) knowledge building actions and interactions, which in turn further lead to structural elaboration and modification, to elaborate and modify existing structures and create new ones. The updated structures become part of the context for the subsequent agency-driven knowledge practices. The development of structures, as described above, involved both the appropriation of structures from the large school context and bottom-up emergence of structural construction and elaboration. The structures evolved from a general frame of the overarching area of inquiry to a network of core epistemic objects ("juicy topics"), each of which was elaborated through documenting and framing the related deepening problems, signifying unfolding absences of knowledge. The primary focus of the above structures was placed on the epistemic landscape of the community's practices, signifying what the community was working on and meant to achieve. With this primary focus, the structures further involved (a) the temporal dimension to frame the past progress and future directions; (b) the social dimension about who was focusing on what "juicy topics;" and (c) the pragmatic dimension in terms of the types of inquiry activities to address the unfolding absences of knowledge. ITM provided a systematic organization of the structures by mapping out the unfolding strands of discourse addressing the interrelated epistemic objects, documenting the Journeys of Thinking, and revealing the primary contributors in each thread of inquiry.

Essential to both the co-construction and the use of the structures, students engaged in personal reflective monitoring of the inquiry objects and related progress and directions. They further conducted reflective conversations about what they were researching, through what contributions, and with what connections. As the qualitative analysis of classroom videos and artifacts showed, the reflective conversations supported the bottom-up emergence of structures and reflective use of collective structures by the members: formulating shared objects of inquiry that rose above the personal questions and interests, organizing members' contributions to each area as an idea thread, and using the map of idea threads to monitor the progress of the whole community and guide members' personal participation and collaboration. Such reflective conversations led to the elaboration of collective structures, as a social outcome, reified and materialized through structure-bearing artifacts (e.g. the map of ideas threads on ITM and the concept map of the interconnected "juicy topics"). The reflective conversations supported by ITM offer a means to enacting metadiscourse, to monitor and plan for collective progress as a whole community (Scardamalia, 2002; van Aalst, 2009; Zhang et al., 2009). The metadiscourse is not only a process for shared monitoring and regulation of collaborative inquiry (Järvelä & Hadwin, 2013) but also leads to an emergent social outcome: collective structures of inquiry, which are continually elaborated, adapted, and used by the students and their teacher to guide their participation.

As the video analysis suggests, the teacher in classroom A played various important roles in the co-construction, adaptation, and reflective use of the collective structures. These included:

(a) mediating the appropriation of structures from the school's contexts, (b) seeding potential epistemic objects through learning materials and activities, (c) facilitating and modeling reflective conversations to frame "juicy topics" as core epistemic objects and organize idea threads, (d) capturing and reifying the structures emerged using online and classroom artifacts, and (e) ongoing referencing of the structure-bearing artifacts in the classroom to guide student reflection and participation and to support the meaningful use and adaption of the structures.

The Role of ITM-Support Reflective Structuration in Sustaining Knowledge Building

The findings show that with ITM-supported reflective structuration, students in classroom A engaged in more active, connected, and productive knowledge building discourse than those in classroom B (Table 5). As a result, they achieved deeper and more coherent understanding of a broader range of topics about electricity. These results are congruent with our previous findings suggesting an increased level of connectedness and depth in the online discourse enabled by ITM-aided reflection (Chen et al., 2013; Zhang et al., 2014).

The specific enhancements observed in the knowledge building processes and outcomes of classroom A are coherently associated with the ways students co-constructed and used the collective structures. First, consistent with the focus of reflective structuration on framing "juicy" epistemic objects and the related gaps of knowledge, classroom A had a higher proportion of notes identifying questions about the various topics. Particularly, classroom A's notes involved more explanation-seeking (as opposed to fact-seeking) questions and idea-deepening questions in search of underlying reasons, mechanisms, and connections. In the Journey of Thinking syntheses of their idea threads (e.g. Table 4), students documented "big ideas" learned, co-defined deeper problems, and further highlighted inquiry actions to be taken. The deepening goals and action plans served to guide individual and collaborative efforts to address the questions through further actions such as reading, experiments, and collaborative work. These actions were reflected in the online discourse through the productive patterns of contributions, including using evidence to examine explanations and integrating and applying related ideas to address challenging issues (Table 5).

As noted above, an important aspect of the structural elaboration was to frame the relationships among the different strands of inquiry (see Figure 3) and use the map of cross-thread connections to plan for deeper inquiry and collaboration. Such efforts contributed to enhancing students' online discourse: There were more extensive build-on connections among student ideas in classroom A; moreover, extensive cross-thread connections were built through the bridging notes that discussed multiple topics about electricity in relationships. As Figure 4 shows, the discourse about voltage/charge and electrons was most extensively connected with the other topics of inquiry, such as batteries, light, energy, magnets, and static electricity.

The enhancements to the knowledge practices and discourse led to improved knowledge outcomes as measured based on student summaries of what they had learned. With students actively monitoring the "juicy topics" as a whole community, each student in classroom A was able to understand more topics of electricity, benefiting from the collective work of their community. As a result of their efforts to identify and address deep exploratory questions, students in classroom A showed a higher level of complexity in their understanding of the topics about electricity, providing elaborated explanations beyond factual descriptions. Mirroring classroom A's connected discourse that linked different topics to electrical charges and electrons, more students in classroom A explained the various topics about electricity based on negative and positive charges (category 2) carried by electrically charged particles (category 3) (Figure 5). These notions represent deep understanding of how electricity works in this age level (Borges &

Horizonte, 1999).

Conclusions and Implications

Expanding our previous studies, the results of this research provided an elaborated account of the formation and elaboration of collective structures, which involved shared interpretative frames about the interconnected epistemic objects and unfolding strands of inquiry. The formation and elaboration of the structures was largely achieved through reflective conversations of the community facilitated by the teacher. ITM and other structure-bearing classroom artifacts were used to make the emergent structures visible. The structures were then used as a means of monitoring collective progress and deliberating deeper questions and inquiry actions, which led to further structural elaboration and adaptation. With the co-construction and reflective use of the collective structures of inquiry, students were able to make more active and connected contributions to the online discourse to investigated the epistemic objects of their community, leading to deeper and more coherent understandings of the electrical topics.

This study is exploratory and has a number of limitations. First, the analysis of the reflective processes to co-construct collective structures was primarily focused on the whole class reflective conversations without detailing the reflective processes undertaken by individuals and small groups. Second, the examination of the impact of reflective structuration was based on the comparisons between two classrooms taught by two teachers. The teachers both had experience with inquiry-based knowledge building pedagogy and their students had been studying using Knowledge Forum for a number of school years. However, we could not exclude other possible variations between the two classrooms, such as the teachers' specific teaching styles and student characteristics that were not analyzed in this study.

Although we are only beginning to understand the reflective structuration of knowledge practices among students, this line of work shows promise to advance Knowledge Building pedagogy and collaborative learning research. Knowledge Building pedagogy places a central focus on continual idea improvement driven by student epistemic agency and adopts a flexible, principle-based approach to classroom design. It is unclear how the agency-driven interactive actions and ideas input from students may be translated into a coherent and productive system of knowledge practices and be sustained over time without extensive teacher pre-scripting. This research sheds light on the reflective, interactional processes to co-construct collective structures as a social epistemic mechanism for knowledge practices to unfold, sustain, and refine over time. Collective structures of knowledge practices represent an important conceptual construct that complements agency-driven creation of collective knowledge in understanding how knowledge building communities operate. Such structures are co-constructed on the basis of existing structures appropriated from prior practices in the larger contexts and are re-constructed in response to new opportunities and conditions created in the ongoing actions and interactions. They provide shared frames about what the community should focus on, how research and collaboration should be done, and through what collaborative roles. Once such structures have emerged, they both constrain and empower student participation and interaction: They signify and imply the scope, directions, connections, and patterns of inquiry activities that the community values, provide organizers and guidance for students' planning and reflection, and serve as a framework for the community to review its collective progress and contributions. Equipped with deeper knowledge about reflective structuration, we will be able to put together systematic designs and support to help teachers master the dynamic practices of knowledge building in which students take on high-level collective responsibility for charting the courses of deep inquiry and sustained discourse.

For the broader research on collaborative, inquiry-based learning, a common understanding is that inquiry-based processes need to be guided and supported to be effective (Hmelo-Silver et al., 2007). However, there are ongoing debates about how much structure and guidance should be provided to support collaboration and inquiry while avoiding over-scripting the processes (Dillenbourg, 2002) and limiting student creative agency. Beyond examining the optimal level of designed/given structures, this research highlights the importance of social structures co-constructed by students, facilitated by their teacher, as a mechanism to leverage student high-level agency and reflection in collaborative knowledge practices. Deeper research is needed to understand how students work as a community to co-construct, use, and adapt collective structures to sustain and deepen their knowledge practices and what pedagogical and technology support can enhance the reflective structuration process to foster self-sustained inquiry and collaboration.

As a related point, reflective structuration connects with the recent research on socially shared regulation of collaborative learning. Learners plan, monitor, and adapt collaborative processes to optimize personal contributions to collective outcomes (Järvelä & Hadwin, 2013). However, existing research in this area has been focused on how learners regulate their participation within designed structures, that is, "regulating how to follow the directions, divide up task components, or complete superficial task components" (Rogat & Linnenbrink-Garcia, 2011, p. 394). This study highlights a social epistemic mechanism of regulation mediated through co-constructed social structures. Beyond reflective regulation based on existing structures, active agents contribute to the creation and adaptation of collective structures to support and transform their practices. As Smith (1983) put it, "The intentionality of actors becomes objectified within social structures which have the capacity to affect the future intentionality of actors" (p. 13).

This research also suggests opportunities to expand online environments for collaborative learning and knowledge building. Current collaborative online environments provide tools and scaffolding to support productive patterns of collaborative discourse. On top of the distributed interactive discourse, ITM showcases possible designs to incorporate a meta-layer in collaborative learning environments: to build collective structures of knowledge practices that make the epistemic landscape and unfolding strands of inquiry visible in a community. Such structures can support student reflective monitoring and conversation about their community's goals, progress, connections, and deepening actions. In this study, the design of ITM was still limited in the seamless integration between the meta-layer structures (e.g. map of idea threads) and the space of ongoing discourse. The teachers and students used a set of classroom artifacts to complement ITM, such as using the printout of the online discourse to review "juicy topics" and using a chart paper to compile the deep problems documented in the Journeys of Thinking. The process to identify online discourse contributions related to each "juicy topic" was also time-consuming. Since the completion of this study, our team has devoted major efforts to refine the design of ITM. We refined the structural representations of idea threads to enable intuitive connections with the ongoing online discourse, and incorporated automated analysis (e.g. topic modeling) to support the monitoring of emergent structures in online discourse, such as core epistemic objects and unfolding strands of inquiry. Guided by these structures, a cross-community space is further provided for students to view into the knowledge practices of different classrooms and engage in cross-community interactions (Zhang, Bogouslavsky, & Yuan, 2017). We hope that these conceptual and technological advances aligned with the reflective structuration framework will contribute to the efforts of the larger field to leverage deep transformation of educational practices drawing upon insights gained in computer-supported collaborative learning and knowledge building.

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Figures

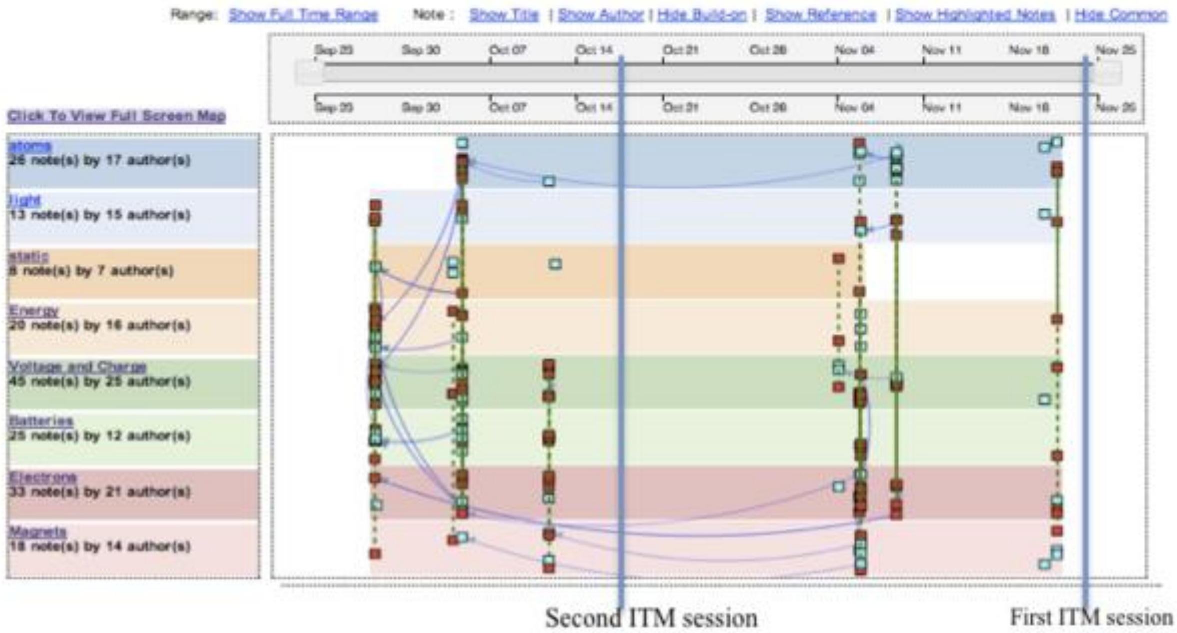


Figure 1. A map of idea threads created by a Grade 5/6 classroom studying electricity. Each colored stripe represents an idea thread. Each square represents a note. A line between two notes represents a build-on link. A dotted vertical line shows notes shared between different threads discussing interrelated objects. The user can hover the mouse over a note to preview its content and open an idea thread by clicking its title.

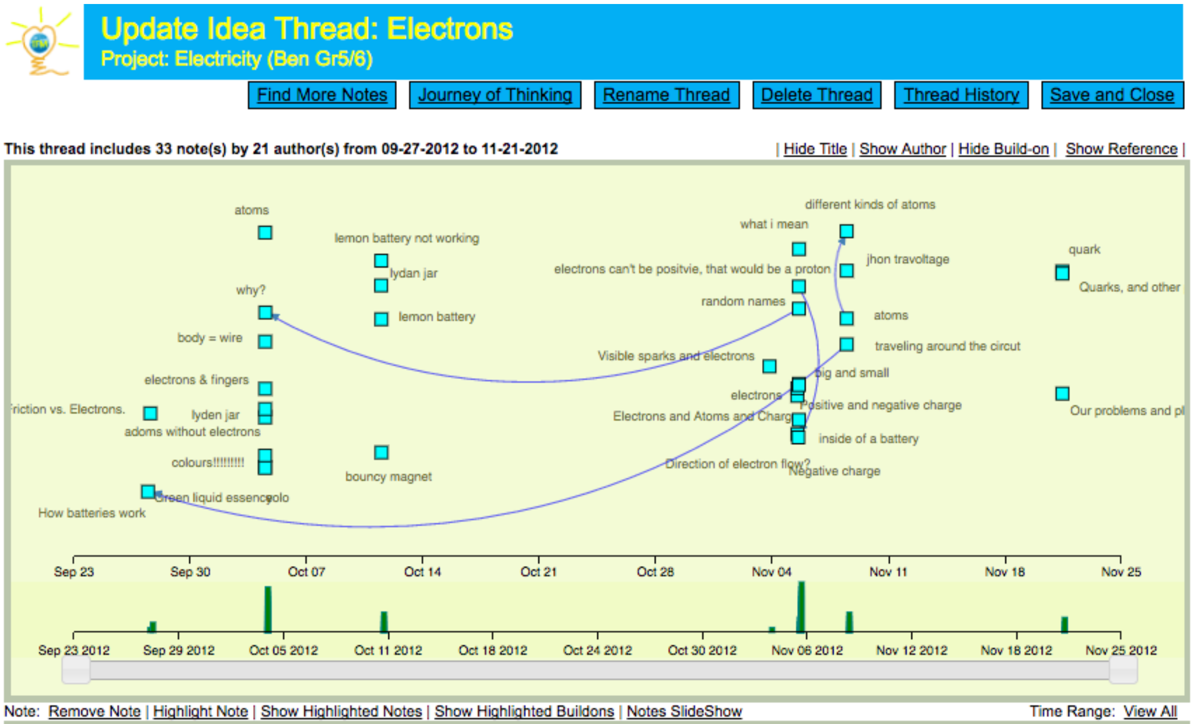


Figure 2. An idea thread showing the unfolding strand of discourse about electrons in the whole inquiry of electricity. Each square represents a note. A line between two notes represents a build-on link.

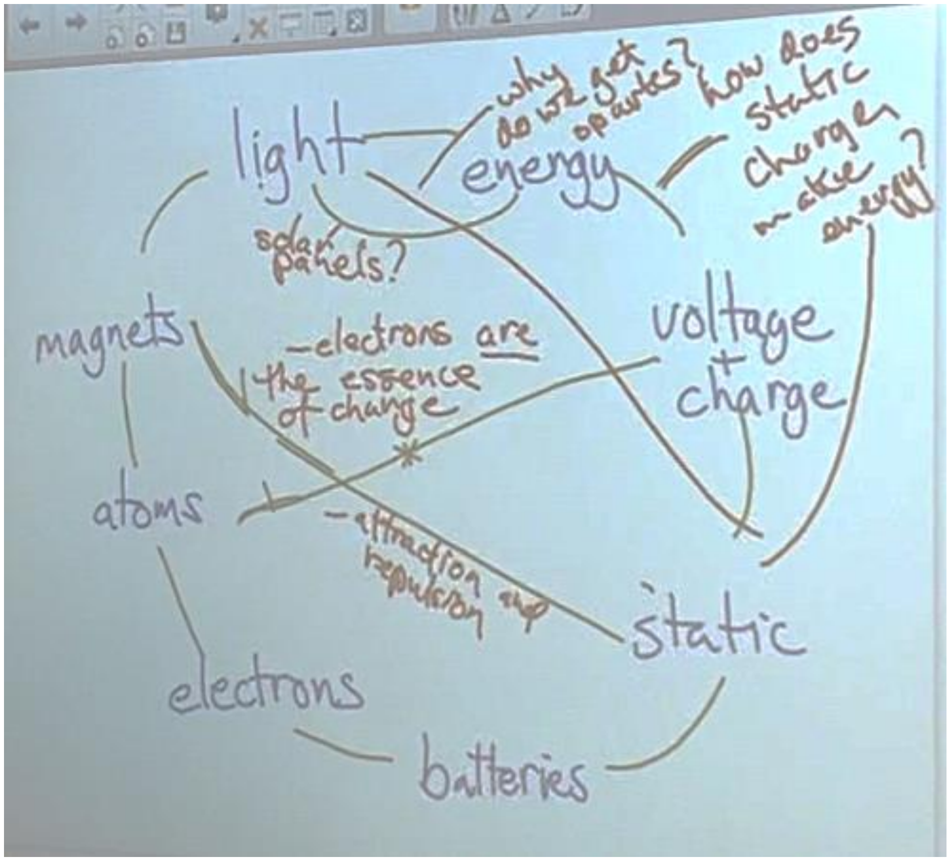
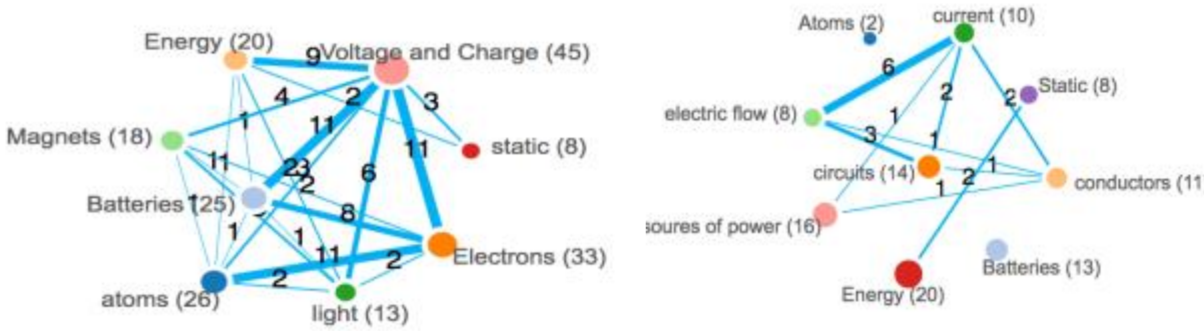


Figure 3. Visual notes of student discussion on the interconnectedness of the eight inquiry topics.



Classroom A Classroom B

Figure 4. Connections across idea threads through the "bridging notes" that simultaneously addressed multiple topics of inquiry. The number after each thread topic denotes the total number of notes included in the thread, and the number on each line shows the number of bridging notes involved between the two linked topics.

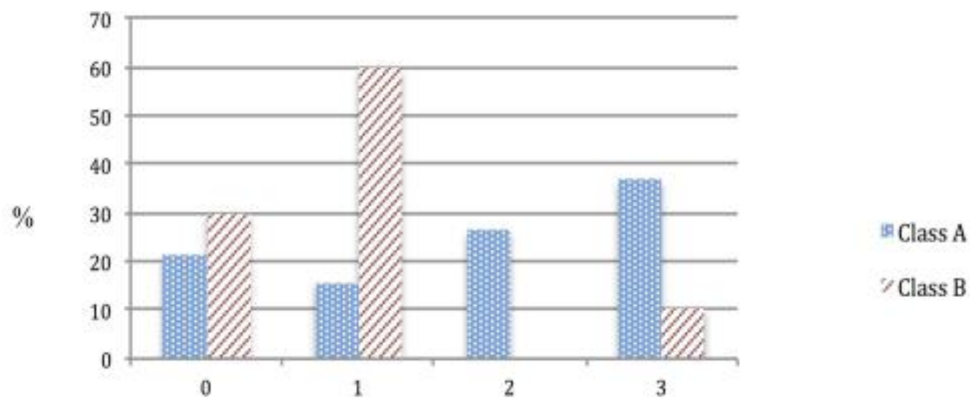


Figure 5. Percentages of students giving different explanations of electricity. The categories include: 0 - no explanation given; 1 - electricity as flow of energy; 2 - electricity as positive and negative charges and currents; and 3 - electricity as the movement of electrically charged particles.

Table 1

Coding of Online Knowledge Building Discourse

Discourse move	Definition	Example
Questioning	Raising questions on online post.	
Fact-seeking questions vs. explanation-seeking questions	Questions asking for factual information vs. those asking for reasons, processes, mechanisms and relationships, and ways to make things work.	Fact-seeking: Does all kinds of fabric cause static electricity? explanation-seeking: [I need to understand] how magnets work. I know that medal is attracted to it but I have no idea why this happens.
Initial wondering questions vs. idea-deepening questions	Questions that search for general information about a topic involving limited prior knowledge vs. those searching for deeper understanding on the basis of information collected.	Initial wondering: I need to understand how batteries work. Idea-deepening: [I need to understand] why electrons flow from the negative side of the battery to the positive side. Why not the other way?
Explaining/theorizing	Statements that explain the processes or reasons underlying certain phenomenon or issue based on personal experience or research.	Whenever you charge one thing positively, you are always charging the other object negatively. If you rub a glass rod with silk, the glass becomes positively charged and the silk becomes negative. It's because the electrons move from one to the other.
Using evidence	Statements that describe experiments, observations, and other sources of data to support or challenge an explanation.	When I connected a battery to lemon juice with wires, the lemon juice slowly started to turn into goop on the positive wire. I think that lemon juice has a negative charge, so, it compressed onto the wire. I think that this also has something to do with the fact that lemon juice is an acid.
Integrating and applying	Statements that connect different ideas and topics to generate a synthesis, a high-order conceptualization, or a solution to address certain challenges.	Electrons are the essence of charge. Atoms are the root of everything having to do with electricity. All the threads are related back to atoms. If nothing related to atoms then everything would be nothing. Atoms are the essence of life and everything is atoms.

Table 2

Coding of Explanations of How Electricity Works

Category	Description
0. No explanation	Students mention related facts or terms, but no explanation is provided about how electric circuits work.
1. Electricity as flow of energy	Students describe batteries as the source of energy that provides electricity. Electricity flows through wires/conductors to the light bulb. No explanation is given about the mechanism and processes related to negative and positive charges.
2. Electricity as positive and negative charges/currents	Students explain the flow of electricity in terms of positive and negative charges or currents. For electricity to flow, the wires need to connect both positive and negative terminals of the battery towards the bulb to form a closed circuit.
3. Electricity as movement of electrically charged particles	Students mention positive and negative charges and further understand them in terms of the movement of electrically charged particles including protons and electrons. Battery is seen as an active source of electricity by means of chemical reaction enabling the movement of electrically charged particles.

Table 3

Processes by Which Classroom A Constructed Structures of Inquiry

Actors and actions	Structures created/adapted through the actions	Tools and resources
Week 1: The teacher introduced electricity as the overarching area of inquiry based on the school's curriculum while leaving specific topics and directions open.	- Naming the overarching area of inquiry; - Creating the Electricity view (workspace) for online discourse.	- Curriculum guidelines; - Knowledge Forum: the creation of the Electricity view.
Ongoing: Individual students encountered and noticed various potential objects of inquiry in hands-on experiments, reading materials, and online and face-to-face discourse.	- Individual questions about various electrical objects and topics.	- Knowledge Forum: note-writing scaffolds - Science notebooks: recording both ideas and questions.
Week 4: The whole class reviewed individual questions and ideas to formulate "juicy topics," as the high-potential epistemic objects for the community to work on. Then, students worked in small-groups to organize the online discourse contributions for each epistemic object, as an idea thread.	- A collective list of eight "juicy topics" under the overarching inquiry area of electricity; - Idea threads representing the unfolding strands of inquiry.	- Smart Board and paper: Visual labeling of topical clusters on the projection and print-out of the Electricity view; - ITM: Idea thread creation and review.
Week 4 and then ongoing: Using idea threads as a structure to monitor collective progress and envision deepening goals and inquiry activities. The teacher mapped out the eight idea threads and facilitated a reflective conversation about the progress and directions. Students co-authored/updated Journey of Thinking syntheses to highlight the "big ideas' learned and absences of knowledge to be addressed.	- Clusters of interconnected idea threads; - Journey of Thinking syntheses of each idea thread, highlighting the "big ideas' learned, deeper problems to be addressed, and actions to be taken; - A compiled list of deeper problems to be addressed.	- ITM: Idea thread maps; -ITM: Journey of Thinking and related scaffolds; - A chart paper recording the list of deeper problems.
Week 5 and then ongoing: Adapting and re-framing the idea threads based on new practices and progress. Both the students and their teacher talked about what each line of inquiry was about and how the different lines of inquiry related to one another.	- Cross-thread connections; - Deeper framing of the specific topics from the perspective of elective charges and electrons.	- ITM: Journey of Thinking about "big ideas" learned; - ITM: visualizations of cross-thread connections; - Visuals created to show how the topics relate to one another.

Table 4

The Journey of Thinking Synthesis on Magnets Organized as Three Sections

Our Problems	"Big ideas" we have learned	We need to do more
-We need to understand how magnets relate to electricity -why do magnets throw compasses off? - how do magnets work?	- That magnets produce an invisible magnetic field. - Magnets have two sides, one positive one negative.	-I think that we should experiment with different types of metal to see which ones are more magnetic. - We need to understand the connection between magnets and electricity by looking on the Internet…

Table 5

The Number and Percentage of Online Posts Involving Various Discourse Moves

Class	**Questioning**	*Fact-seeking questions*	*Explanation-seeking questions*	*Initial wondering questions*	*Idea-deepening questions*	**Explaining**	**Evidence**	**Integrating and applying**
A	53 37.86%	9 6.43%	45 32.14%	16 11.43%	37 26.43%	85 60.71%	17 12.14%	14 1.00%
B	22 20.37%	7 6.48%	16 14.81%	18 16.67%	4 3.70%	78 72.22%	2 1.85%	1 0.09%