Fostering Sustained Knowledge Building through Metadiscourse Aided by the Idea Thread Mapper

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Abstract: This study was conducted in two Grade 5/6 classrooms that studied electricity over a three-month period using Knowledge Forum. Classroom A used Idea Thread Mapper (ITM)—a timeline-based collective discourse mapping tool—to engage in ongoing metadiscourse to review collective advances and gaps. Classroom B did not engage in this reflective practice until near the end of the inquiry. The results show that members of class A had more comprehensive and coherent awareness of the various inquiry themes discussed by their community focusing on deep conceptualization of electricity. Informed by the reflective awareness, classroom A also engaged in more active and connected online discourse to address deepening issues and develop coherent explanations across different lines of inquiry.

Keywords: metadiscourse, Idea Thread Mapper, knowledge building, collective responsibility

Introduction

Education to cultivate creative knowledge practices needs to support a progressive, collective trajectory of inquiry sustained over a long term for productive effects (Engle, 2006; Hakkarainen, 2003; Zhang et al., 2014). Students engage in sustained inquiry and knowledge building discourse: They contribute diverse ideas to ongoing conversations and collectively advance the ideas through constructive criticisms, mutual build-on, and progressive problem solving, with new and deeper challenges identified as their understanding advances (Bereiter, 2002). To enable a progressive, collective trajectory of inquiry, classrooms need to give student ideas a public representation, as part of collective knowledge (Bereiter, 2002). Various collaborative environments have been created to give student ideas an extended social life beyond segmented tasks and activities, so the ideas can be continually revisited, improved, and built upon by community members for deeper understanding. Despite the above potential support, current online environments lack effective means to represent collective knowledge growing in extended discourse. With ideas distributed across individual postings and responses over time, it is hard for students to understand the conceptual landscape and trajectories of their collective work, causing short-threaded discourse that lacks connected deepening moves (Hewitt, 2001; Suthers et al., 2008).

This research explores classroom designs to foster sustained knowledge building using the Idea Thread Mapper (ITM), a timeline-based collective discourse-mapping tool created by our team to make collective trajectories in online discourse visible for ongoing reflection (see Figure 1 for a map of idea threads).

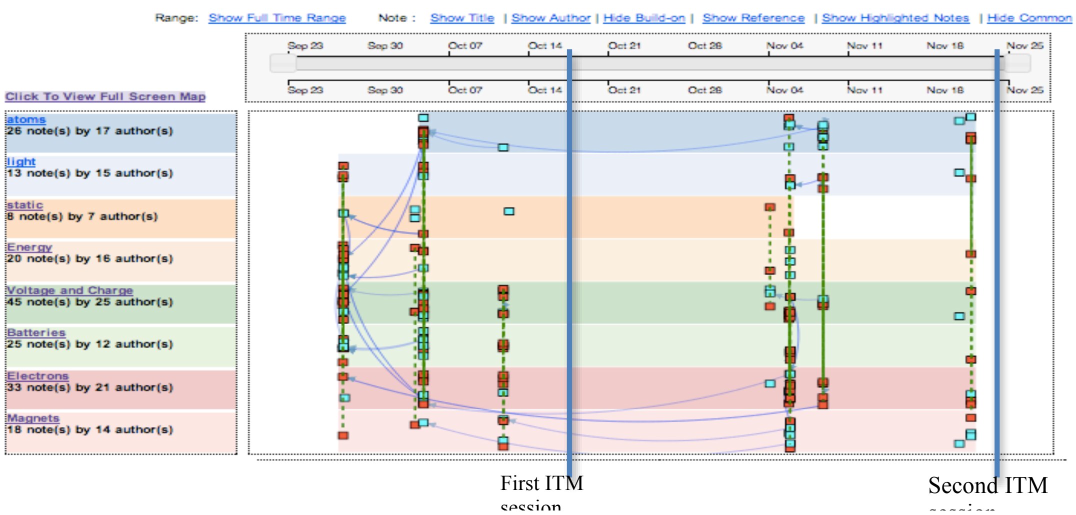

Figure 1. A map of idea threads created by a Grade 5/6 classroom studying electricity

ITM Interoperates with Knowledge Forum (Scardamalia, 2002) and potentially other platforms for collaborative knowledge building. 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, we introduced "idea threads" or "inquiry threads" (Zhang et al., 2007) as a larger, emergent unit of ideas in online discourse. Each idea thread is composed of a sequence of discourse entries (possibly involving several build-on trees) contributed by a subset of the members of a community to address a shared problem or discourse topic, such as batteries and other topics in Figure 1. ITM allows students to define focal problem-based topics and select important discourse entries addressing each topic. The discourse entries in each idea thread are displayed on a timeline with the authors and build-on connections identified. The knowledge progress in each idea thread is further made transparent by students through co-authoring a "Journey of Thinking" synthesis aided by a set of scaffolds (e.g., *We want to understand, We used to think…we now understand…, We need to do more*). Idea threads and thread-based syntheses are co-editable by members of the classroom, with each version recorded for later review. The collective knowledge of the community in a whole inquiry is further represented as clusters of idea threads (Figure 1) that address interrelated problems through connected efforts of the members. In Figure 1, each colored stripe represents an idea thread extending from the first till the last note contributed addressing its focal problem/topic. Each square represents a note. A blue line between two notes represents a build-on link. A dotted vertical line shows notes shared between different threads discussing interrelated issues. By examining this cluster of idea threads, students can reflect on their contributions, cross-thread connections, and weak areas that need deeper work.

Sustained knowledge building requires students to take on collective responsibility for progressively defining what they need to further understand as their collective understanding advances (Scardamalia, 2002). Students face the challenge to enact collective regulation of long-term knowledge building: to construct shared goals, formulate plans of actions, monitor collective progress and engagement, and adapt collaborative processes to optimize members' contribution to achieving their shared outcomes (Järvelä & Hadwin, 2013; Zhang et al., 2009). ITM-based designs support students' collective regulation of long-term knowledge building through metadiscourse: metacognitive conversations about the ongoing inquiry and discourse focusing on high-level decision making, including collective goal formulation, progress review, and co-planning (Zhang et al., 2009, 2014). Such metadiscourse is critical to knowledge building, but it is rarely observed in inquiry-based settings (Scardamalia, 2002; van Aalst, 2009). ITM-based metadiscourse is organized to support talk-organizing and talk-evaluating functions (cf. Vande Kopple, 1985): to frame and review ongoing discourse contributions based on shared focuses and goals, to monitor progress in each unfolding lines of inquiry, to synthesize insights and identify gaps and deeper actions. Through metadiscourse, students generate high-level reflective representations of their ongoing discourse to guide sustained inquiry and coherent discourse.

The current study is part of a multi-year design-based research to understand the operation of metadiscourse and its role in helping students co-monitor and advance their collective knowledge. In the first iteration, we conducted a set of studies in a Grade 3 and two Grade 5/6 classrooms. The results elaborated the process and benefits of ITM-aided metadiscourse, which helped fostering student awareness of collective progress beyond individual focuses and informing sustained and connected discourse to address deepening questions, leading to sophisticated explanations of complex issues (Zhang et al, 2013, 2014). However, these findings were generated through exploratory studies without cross-condition comparison. Also, the ITM-aided metadiscourse was implemented as a single classroom session. Further expansions need to organize it as a formative, ongoing effort while enabling easy connections between ITM-aided metadiscourse and ongoing online discourse. The current study, as the second iteration, aims to address these needs. Our research question asks: In what ways does such ongoing metadiscourse help students to monitor diverse inquiry themes evolving in their community's discourse and formulate connected, progressive discourse for deep understanding?

Method

Classroom contexts and implementation

This study was carried out in two Grade 5/6 classrooms, with 21 students in classroom A and 22 in B. The two classes were taught by two experienced teachers, respectively, each having multiple years of experience with facilitating inquiry. Students in each classroom investigated electricity over a 12-week period with two science lessons each week. Their work integrated whole class knowledge building conversations, individual and cooperative reading, student-directed experiments and observations, and so forth. Major ideas, questions, and findings were contributed to Knowledge Forum for continual discourse online. For cross-classroom comparison, the design of ITM-aided metadiscourse and reflection was implemented as an ongoing effort in Class A beginning from the third week of the electricity inquiry; such reflection was only systematically implemented in

Class B in the final phase of the inquiry in Week 9. This time-lag design allowed us to conduct detailed data analysis of Class A to elaborate the ongoing process of ITM-aided metadiscourse while enabling cross-classroom comparisons to examine the impact of ITM-aided metadiscourse on student knowledge building. The knowledge building work unfolded as a continuous process; for the purpose of data analysis, we identified three phases, as elaborated below.

Phase 1 (weeks 1-3), as the baseline

This phase extended from week 1 to 3 till Class A implemented its first ITM reflection session. Examining student interaction in this phase when ITM was not yet used in either classroom provided the baseline data about student knowledge building facilitated by the two teachers. In both classrooms students began their electricity inquiry with hands-on explorations of static electricity, circuit and conductors, and magnets. They discussed their findings in small groups and further shared their questions and ideas through whole class knowledge building conversations. 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.

Phase 2 (weeks 4-8), as the focus of the data analysis and comparison

This phase extended from Class A's first ITM reflection session to its second ITM session till Class B conducted its only ITM session. Comparing student engagement in this phase between classroom A and B helped to examine the impact of ITM reflection on sustained knowledge building. By the end of the third week, students in class A had created 89 notes in their Knowledge Forum view. They conducted the first ITM session to review collective progress. The whole class made an initial pass to co-review their Knowledge Forum view (discourse space) projected on a screen to identify high-potential "juicy topics" that had been discussed. Students were then given a printout of their Knowledge Forum view, which served as a bridging artifact to support metadiscourse about their online written discourse. They worked in small groups to identify note clusters that discussed various topics, marking different clusters using different colors. The whole class then convened to discuss the topics identified, leading to the creation of a collective list of eight "juicy topics" highlighting problems related to batteries, static electricity, magnetism, electrons, atoms, voltage & charge, energy sources, and light. The students then formed into topic-based voluntary groups, each of which constructed an idea thread for a topic using ITM. Members of each group decided keywords to be used to search for related Knowledge Forum notes and found and selected the notes that addressed the focal topic. This session was concluded with a whole class conversation to examine the map of idea threads (see Figure 1 till the first ITM session) and reflect on community-wide advancement, cross-theme connections, and weak areas. Students realized that the different idea threads all have connections with electrical charges carried by electrons and protons. This fundamental understanding was later diffused to the inquiry and discourse about a wide range of specific topics such as static electricity, batteries, lightning, and so forth. With deeper inquiry and discourse carried out in the subsequent three weeks, students in class A conducted the second ITM reflection session in which they updated each idea thread by including new Knowledge Forum notes addressing the deeper issues (see the threads extended after the first ITM session in Figure 1). Consolidating their reflection, students further worked as small groups to create a "Journey of Thinking" synthesis for each idea thread using a set of scaffolds that highlighted problems of understanding, collective progress, and deeper issues.

Phase 3 (week 9-12), final research and presentations

Following similar procedures, students in class B implemented ITM-aided reflection to review their online discourse as idea threads and authored Journeys of thinking syntheses to summarize their advances and deeper issues. In the rest of the inquiry, students in both classrooms concentrated on classroom-based inquiry to understand the deep issues identified through ITM reflection and preparing final presentations to share new knowledge about these issues. With these efforts mostly enacted as face-to-face activities, students contributed a limited number of notes online in this phase. Therefore, we did not conduct statistical analysis for this phase.

Data analysis

Video analysis of the ITM-aided metadiscourse is reported in Zhang et al. (2015), which elaborates the processes of metadiscourse for ongoing regulation of knowledge building: to formulate shared focuses and goals as emergent from diverse discourse input; to review contributions, advances, and deeper issues in each line of work focusing on a high-potential topic; to examine clusters of idea threads and synthesize community-wide advances, connections, and challenges, and to plan deeper efforts as individuals and spontaneous groups to address the community's needs. The analyses in this paper focus on the role of metadiscourse to help students monitor diverse evolving themes of inquiry and formulate connected deepening discourse.

Content analysis of individual portfolio summaries

To examine students' reflective awareness and understanding of the various inquiry themes in their community's discourse space, we asked each student in classroom A and B to summarize what they had learned around the midpoint of the inquiry (after class A's first ITM session). Each student's summary was coded through content analysis (Chi, 1997). Specifically, two analysts 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 ten topics created (e.g. batteries, static electricity, voltage and charge, atoms). A primary coder then read each portfolio summary to identify utterances related to each of the focal topics. The ideas related to each focal topic were further coded based on epistemic complexity and scientific sophistication using coding schemes validated through our previous studies (Zhang et al., 2007). 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 goal of science (Salmon, 1984). 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. Considering these two scales as ordered and continuous, we assessed the inter-rater reliability using Pearson correlation, which was found to be 0.88 for epistemic complexity and 0.89 for scientific sophistication between two independent coders.

Beyond student understanding of each individual topic, we analyzed the level of coherence in explaining different topics focusing on the nature of electricity. Borges and Horizonte (1999) identified increasingly complicated mental models about how electricity works: a general conception of electricity as the flow of energy often found among young students, a more informed conception focusing 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 topics that share the same mechanisms. In light of these mental models of electricity, we created a coding scheme (see Table 1) to categorize each student's explanations across topics such as electric circuits, conductors, batteries, current, and charges. Table 1 does not include electricity as a field phenomenon (category 4) because none of the students showed this understanding that is far beyond the level of Grade 5/6. Two raters independently coded 21 portfolio summaries resulting in an inter-rater agreement of 95.24% (Cohen's Kappa = 0.97 for this category-based coding).

Table 1: Progressively more complicated explanations of how electric circuits work

Category	Description
0. No explanation	Basic facts or terms only, without explanations 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.
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.

Quantitative analysis of student contribution and interaction in the online discourse

Using the analytic toolkit underlying Knowledge Forum, we retrieved quantitative data about student note contributions and build-on links in each phase of the inquiry. Comparing the level of contribution and interactivity between the two classrooms especially for Phase 2 helped us to gauge the benefits of ITM reflection in sustaining active and connected knowledge building discourse.

Qualitative tracing of idea improvement in each idea thread as related to students' final presentations

To understand the specific ways in which ITM-aided metadiscourse fostered coherent efforts of sustained knowledge building, we qualitatively analyzed the online discourse in the idea threads organized by students in classroom A in comparison to the online discourse of classroom B. Following inquiry thread analysis (Zhang et al., 2007), we used each idea thread topic defined by students as a "tracer" to trace interactive ideas and questions contributed to the online discourse over time before and after the ITM reflection sessions in relation to the classroom inquiry activities observed. For each idea thread, two researchers co-read the notes in a chronological sequence to develop an overall sense of visible idea-advancing changes. They further identified new questions and ideas in the online discourse before the first ITM reflection session, during ITM reflection in the ITM Journey of Thinking synthesis, in the online discourse after the first ITM reflection, as well as in students' final presentations sharing deeper knowledge about each topic. The ideas and questions were compared between the different phases of inquiry and linked across different idea threads to identify salient idea-advancing patterns by which students went beyond the existent information in their community to develop more advanced concepts and frame unfolding trajectories and directions to guide coherent contributions.

Results

Content analysis of student summaries

The content analysis of student summaries examined student awareness of the inquiry topics addressed by their community and their understanding of each topic based on epistemic complexity and scientific sophistication. Through ITM-aided reflection, students in classroom A were able to summarize more topics of inquiry 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 (including 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 ($M = 3.49$, $SD = .53$) to explain the mechanisms, processes, reasons, and relationships beyond factual descriptions ($F(1,36) = 6.51$, $p = .015$).

We further coded the coherent explanations of students across specific topics based on progressively advanced models about how electricity works (Figure 2). The proportions of students coded for the different categories of explanations (see Table 1) differ significantly between the two classrooms ($X^2 = 16.03$, $df = 3$, $p = .001$). Classroom A had higher percentages of students giving advanced explanations that conceive 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 electric circuits at a general level as energy flow from the battery to the light bulb (category 1).

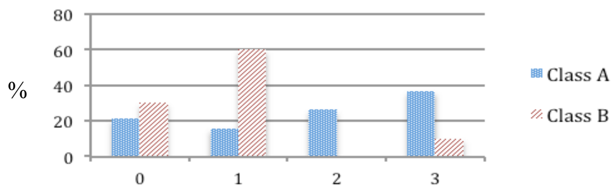

Figure 2. Percentages of students giving different explanations of electricity

Quantitative analysis of student contribution and interaction in online discourse

To gauge student contribution and interactivity in online discourse, we analyzed the number of notes contributed by each student and the percentage of notes in build-on links. Table 2 shows these two measures for each classroom in Phase 1 before ITM use and in Phase 2 after class A started its use of ITM (before class B used ITM). In Phase 1, students in class A contributed more notes to the online discourse in Knowledge Forum than those in classroom B ($F(1,41) = 4.59$, $p = .038$). There was no significant difference in the percentage of notes with build-on links ($p > .10$). These measures of note contribution and linking (build-on) in this phase were included as covariates in the analysis of variance of students' note contribution and linking in Phase 2. Informed by their ITM-aided reflection on their collective knowledge advances, gaps, and connections, students in class A wrote a significantly larger number of notes in Phase 2 than class B ($F(1, 40) = 6.34$, $p = .016$). A significant effect was observed for the covariate of student contribution rate in Phase 1 ($F(1, 40) = 4.08$, $p = .05$). Classroom A in Phase 2 also had a significantly higher percentage of notes with build-on links than classroom B ($F(1, 40) = 6.29$, $p = .016$), with a significant effect observed for students' note linking percentages in Phase 1 as a covariant ($F(1, 43) = 4.45$, $p = .041$). These results demonstrate that the ITM-aided reflection helped class A to sustain more active and connected knowledge building discourse.

Table 2: Contributions to the online knowledge building discourse (means and standard deviations)

Classroom	Phase 1: Week 1-3		Phase 2: Week 4-8	
	Notes written per student	% of notes linked	Notes written per student	% of notes linked
A: ITM Use after Week 3	4.86 (2.61)	37.19 (33.27)	3.57 (3.16)	35.00 (34.00)
B: ITM Use Delayed till after Week 8	3.32 (2.01)	40.23 (29.87)	1.36 (0.67)	15.00 (22.90)

Qualitative tracing of idea improvement across the idea threads

Deepening the quantitative analysis, we conducted qualitative tracing of each idea thread to identify salient idea-advancing patterns by which the community went beyond existent contributions of individual students to develop advanced concepts and frame unfolding trajectories and directions of inquiry.

Conceptual "rise-above" and abstraction

As a primary pattern, students developed their idea trajectories by identifying emergent conceptual constructs as shared objects of inquiry to generate increasingly powerful explanations. The whole inquiry initiative began with student hands-on exploration of batteries, light bulbs, magnets, and static electricity. Students then interacted online to discuss initial observations, questions, and ideas, which became the starters of the idea threads about batteries, static electricity, energy sources, and magnets. Sustaining inquiry in these idea threads, students searched for conceptual explanations of the empirical facts that they had observed. Abstract conceptual constructs developed later became objects of inquiry in their own right, leading to the emergence of idea threads investigating electric charges, electrons, and atoms. For example, students' initial explanation about how batteries work assumed that there would be "mini batteries" inside the batteries to generate energy. This explanation was replaced with better theories, such as: "protons and electrons are…two parts of the battery" that carry positive and negative charges and that there are "a lot of chemical reactions" inside the battery. Interest emerged among the students to understand electrons, atomic structure and protons, and positive and negative charges. Similarly, students' online discourse on fabrics that cause static electricity came across the concepts of negative and positive charges. 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. Through examining their map of idea threads (Figure 1), students noticed deep connections between these concepts and all the other idea thread topics and identified electrons, atoms, and charges/voltage as the areas that needed deeper exploration. Core questions were raised in the Journey of Thinking syntheses regarding these topics, such as: What makes electrons move? What is the connection between atoms and energy? How do atomic bombs work? These areas and questions of inquiry became the focus of the subsequent work. As Figure 1 show, the idea threads about charges/voltage, atoms, and electrons involved the most intensive discourse after the first ITM reflection in mid-October. Deep understandings were shared in students' final presentations that explained atomic structure and how positively and negatively charged particles interact.

Progressive deepening

Students further deepened and sustained their trajectories of inquiry by identifying productive deepening questions as progressive goals in each line of work for specialized investigation. Students in classroom A generated a diverse set of questions through initial hands-on explorations that caught their deep interest. On the basis of these initial specific questions, ITM-aided metadiscourse further fostered students' efforts to formulate deeper questions in light of major conceptual constructs emerged from their discourse, such as electrons and electric charges. ITM's feature of Journey of Thinking scaffolded student efforts to generate progressively deeper questions in light of their advanced understandings. Before class A's first ITM reflection, 38.55% of the notes contained questions, with 15.66% of the notes raising general wonderment questions focusing on broad issues (e.g. what powers a battery?) and 22.89% raising idea-deepening and elaborating questions (e.g. why isn't the iron attracted to the other side of the magnet?). The ITM-aided metadiscourse and reflection explicitly encouraged students to review their progressive questions and ideas in each idea thread and co-author Journey of Thinking syntheses. When co-authoring the Journey of Thinking synthesis for an idea thread as a group, the students discussed their existing questions and summarize the most important ideas learned (e.g. "magnets produce an invisible magnetic field …"). They further selectively highlighted deeper questions to be addressed in each focal area ("we need to understand how magnets relate to electricity"). These deeper questions highlighted for different idea threads were later written on a piece of chart paper as a collective list of problems for their community. Students then formed into voluntary specialized teams to conduct focused research to address these issues. They authored individual and collaborative notes in Knowledge Forum to share findings while identifying even deeper questions. Among the notes written by class A in Phase 2 after its first ITM session, 36.84% raised questions, including 5.26% raising general wonderment questions and 31.58% addressing more specific, idea-deepening and elaborating questions (e.g. why are some metals magnetic and some not?) These showed more active deepening moves than class B that only had 22.22% of notes raising questions in Phase 2.

Conceptual connection and diffusion

As students worked on deepening questions and ideas in each area, they monitored cross-thread connections to advance the community's common ground understandings. Students engaged in reflective conversations to review connections across different idea thread themes, leading to the insight that "everything is connected… electrons are part of atoms and electrons have charge, and so charge is connected to atoms through electrons." This insight in cross-thread connections was further developed and 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."* The understanding of electrical charges in terms of the movement of electrons and protons was used to enrich the discourse across all the idea threads after the first ITM session, with 12.28% of class A's notes in Phase 2 (compared to 1.38% in class B) building cross-topic connections. Important insights were generated, including: *"Electrons are the essence of charge. Atoms are the root of everything having to do with electricity." "Whenever you charge one thing positively, you are always charging the other object negatively. It's because the electrons move from one to the other."* Atom (including electron) was the most frequently mentioned topic in the individual portfolio summaries, with 21 of the 22 students summarizing understandings related to this topic.

Discussion

Through ITM-aided metadiscourse, students in classroom A demonstrated more comprehensive awareness and coherent understanding of the emergent inquiry themes of their community. The iterative processes to review the ongoing knowledge building discourse for shared high-interest focuses, identify related contributions, and synthesize insights and challenges helped the members monitor the unfolding lines of inquiry focusing on core issues about electricity. This finding is consistent with the findings of our first iteration in this design-based research, showing that ITM-aided metadiscourse and reflection helped bring more themes of communal inquiry to the attention of the community members (Zhang et al., 2013). In a knowledge building community that encourages diverse expertise, each student needs to conduct focused (specialized) inquiry with peers to address a few of their communal topics while developing an awareness of the advances of the whole community beyond their own work (Zhang et al., 2007). ITM-aided metadiscourse helps students to address this need through collectively monitoring the unfolding lines of inquiry of their whole community, leading to broadened awareness of various inquiry themes and, more importantly, reflective understanding of cross-theme connections focusing on core conceptualizations (Figure 2).

With reflective awareness of the various lines of work in their community, students in classroom A engaged in more sustained and connected knowledge-building discourse online in the second phase of the inquiry. They contributed more notes to address deeper issues identified for each line of work, and their notes had more build-on links than those created by classroom B (Table 2). These results are also congruent with our previous findings suggesting an increased level of connectedness in the online discourse resulted from ITM-aided reflection (Chen et al., 2013). The ITM-aided metadiscourse to review collective advances, challenges and connections has the potential to help sustain productive online discourse among students, which, in current practice, often lacks active connected contributions and deepening moves (Guzdial et al., 2001). As the qualitative tracing of idea threads suggests, the ITM-aided metadiscourse and reflection could enhance students efforts to continually go beyond existent contributions to "rise above" toward high-level conceptualizations, to generate deepening questions, and to build conceptual connection across different lines of inquiry. The inquiry process initially focused on concrete and tangible aspects of electricity, which needed to be explained using higher-level conceptual structures. The ITM-aided metadiscourse to review core topics of inquiry from the existing distributed discourse helped the students to explicitly define abstract concepts, such as electric charges and voltage, atoms, and electrons, as shared goals of research in their community, leading to intentional and intensive contributions to these areas. Through the ongoing metadiscourse and reflection, students further identified deeper questions and issues as informed by their updated understanding, which brought forth deepening goals for progressive problem solving (Bereiter, 2002). These deepening goals served to guide individual and collaborative efforts to address these questions. The core concepts of electric charges and electrons were diffused to understanding different topics (static electricity, batteries).

In conclusion, the collective metadiscourse supported by ITM serves to represent and guide collective inquiry trajectories in extended knowledge building discourse. To better support reflective metadiscourse about unfolding threads of ideas, we are creating automated analysis to ease idea thread review and further make productive idea threads sharable across communities that learn from and build on one other's progress.

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