Idea Thread Mapper: Designs for Sustaining Student-Driven Knowledge Building Across Classrooms

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Abstract: This research project aims to address the intra- and inter-community challenges associated with student-driven knowledge building over longer terms and across classrooms, in which students take on collective responsibility for charting the course of sustained inquiry and dynamic interaction. We designed the Idea Thread Mapper (ITM) system to support knowledge building in each classroom community as well as idea interaction across communities. At a local classroom level, students engage in focused inquiry and knowledge-building discourse. As their inquiry proceeds, they carry out metacognitive conversations to frame/reframe their collective inquiry directions and processes and synthesize their journey of thinking over time. For cross-community interaction, they selectively share productive idea threads and syntheses in a cross-community space for idea contact with broader knowledge builders. Supported by ITM, we conducted design-based research in a network of Grades 3-6 classrooms. Findings and implications are discussed.

Introduction

Research on computer-supported collaborative learning (CSCL) has made substantial progress in understanding the sociocultural and cognitive processes of collaborative discourse and knowledge building. However, as a field, we still face the challenge of how to enable sustained educational change and transformation in line with the ethos of CSCL (Chan, 2011; Stahl & Hesse, 2009; Wise & Schwarz, 2017). Tackling this grand challenge requires new research-based innovations to extend CSCL to longer timescales and larger social scales (Stahl, 2013), transcending the traditional boundaries associated with curriculum areas and school years. Aligned with these directions, this paper presents our research to create new learning infrastructures and designs for supporting student-driven knowledge building over long terms across classroom communities.

Design efforts to support student-driven, long-term knowledge building in each classroom need to address two competing demands: to provide the needed classroom guidance and, at the same time, to foster students' high-level agency over creative knowledge processes (Zhang et al., 2018). Extensive research has been conducted to scaffold collaborative learning using collaboration scripts, which are pre-designed to specify, sequence, and distribute various actions and procedures among learners in order to guide effective interactions (Kirschner & Erkens, 2013). Scripted collaboration tends to focus on short-term inquiry activities, in which students are given limited responsibility for charting the process of collaboration and inquiry (cf. Wise & Schwarz, 2017). Long-term, creative knoweldge building involves highly dynamic interactions that are difficult to predict and pre-script (Sawyer, 2007). In proudcitve knoweldge building communities, students need to take on collective responsibly for charting the course of sustained discourse and inquiry (Scardamalia, 2002). The inquiry process continually evolves and deepens through members' interactive input (Zhang et al., 2011). Deeper problems and knowledge goals are identified over time as new understandings are developed, driving sustained cycles of inquiry. To guide effective and broad classroom implementation of dynamic knowledge building, new research is needed to clarify how such student-driven, open-ended, interactive processes can become socially organized and pedagogically supported while addressing curriculum expectations and contextual constraints (Zhang et al., 2018).

Efforts to support long-term knowledge building in each classroom can further be supported by a larger social infrastructure that allows productive ideas to flow between communities. Such knowledge infrastructures are essential to the productivity of real-world knowledge communities that work as interconnected fields (Csikszentmihalyi, 1999). It is an unsolved challenge for CSCL research to design such accumulative infrastructures and make each community's knowledge progress accessible to other classroom communities. Existing online collaboration systems can easily create a permanent record of student discourse; nevertheless, the knowledge advances achieved in the discourse are not visible or easily interpretable to outsiders who were not part of the discussion. In practice, online discussion spaces are typically reset each academic year for the new student cohort, dumping out the ideas of the previous students. There are emerging efforts to share online discussion spaces between different communities for collaborative knowledge building (e.g. Laferriere, Law, & Montané, 2012). The dominant strategy is to have the different communities directly view each other's online discussion posts and participate in the same discussion space. However, students often find it difficult to read other communities' online posts and understand their progress and contexts.

The design and research work presented herein aims to address the challenges of how student-driven, long-term knowledge building can be socially organized and how cross-classroom interaction can be supported. Drawing upon our previous research, we designed the Idea Thread Mapper (ITM) system, which was used to conduct design-based research in a network of Grades 3-6 classrooms.

The design of Idea Thread Mapper

Zhang and colleagues have conducted a series of studies to examine how productive knowledge building communities operate for student-driven, continual idea improvement (e.g. Zhang et al., 2007; Zhang & Messina, 2010; Tao et al., 2015). The findings unveiled a socio-epistemic mechanism by which the student-driven, dynamic inquiry process is organized and scaffolded: emergent reflective structuration. Different from pre-scripted guidance structures, teachers and students engage in ongoing reflection on their inquiry and discourse and co-construct various inquiry structures and resources to support their collective work. The co-constructed structures include shared frames and representations about what the community should investigate, how their inquiry and discourse should be conducted, and who will work with whom in what areas (Tao & Zhang, 2018; Zhang et al., 2018). Guided by the co-constructed structures, students monitor their ongoing knowledge building practices and develop coordinated efforts to advance their collective agenda of inquiry without merely relying on the teacher to lead them through the whole process. Based on the insights gained, we designed a new collaboration system: Idea Thread Mapper (ITM, http://idea-thread.net), which interoperates with Knowledge Forum (Scardamalia & Bereiter, 2006) and potentially other collaborative learning platforms. ITM was originally created in 2012 (Chen, Zhang, & Lee, 2013; Zhang et al., 2012) and substantially redesigned and upgraded during 2017-2018. The new ITM incorporates systematic support for co-organizing long-term knowledge building in each classroom community as well as idea interaction across communities. At a local classroom level, students engage in focused inquiry and discourse in their own classroom's discourse space, carry out metacognitive conversations to reflect on shared focuses and insights emerged from the distributed discourse, and synthesize their journey of inquiry including the progress achieved and deeper problems to be addressed. For cross-community interaction, they selectively share productive idea threads and syntheses in a cross-community space for dynamic idea contact with their "buddy classrooms." Across both social levels, students take on high-level responsibility for structuring their unfolding inquiry directions and processes, reviewing progress, and planning for productive collaboration with the support of embedded analytics. Below we summarize the design principles and features.

Principle 1: Reflective structuration: Co-organize the journey of inquiry as it unfolds

Current collaborative online environments in the forms of online forums and chatting lack support for students to structure and monitor their unfolding, collective journey of inquiry. Students' online discourse tends to focus on teacher-assigned topics and tasks. Also, with students' diverse idea input recorded in distributed online postings, it is often difficult for students and their teacher to monitor the collective knowledge progress achieved in the online discourse (Hewitt, 2001; Suthers, Vatrapu, Medina, Joseph, & Dwyer, 2008; Zhang, 2009). Therefore, to better support students' reflective monitoring and co-organizing of their collective inquiry, ITM incorporates meta-layer representations of student-constructed inquiry structures on the top of the distributed online discourse. The meta-layer inquiry structures serve to capture students' shared directions of inquiry emerging from their interactive discourse, visualize the unfolding strands of inquiry, and document shared progress in each strand of inquiry to inform students' deepening work. The specific features include:

(a) <u>Co-organizing shared wondering areas and inquiry threads</u>: As a high-level structure to guide each knowledge building inquiry that may last over several months, students co-organize their shared wondering areas and specific threads of inquiry (Figure 1) as their work proceeds. Each wondering area is a major direction of inquiry (e.g., brain), which is identified by the classroom members based on their interests and questions. Under each wondering area, members develop one or more inquiry threads, each of which investigates a more specific problem or challenge (e.g. How does the brain work to control body movement?) related to one (or more) wondering area. The wondering areas and threads of inquiry are emergent, co-formed structures, which are similar to "desire lines" —as apposed to pre-planned paths—formed in public spaces (Zhang et al., 2018). In a knowledge building initiative, students begin with open exploration and discourse to develop initial ideas and questions. Through monitoring emerging inquiry interests and evolving needs, they identify high-potential wondering areas and set up idea thread focus, which guide their collaborative discourse and joint inquiry to advance their understandings while continually identifying deeper problems. Each student can select one or more wondering areas as his/her primary focus of inquiry, and adjust his/her focus as the inquiry unfolds.

Students with shared interests form into spontaneous flexible groups to conduct collaborative inquiry and advance their understandings.

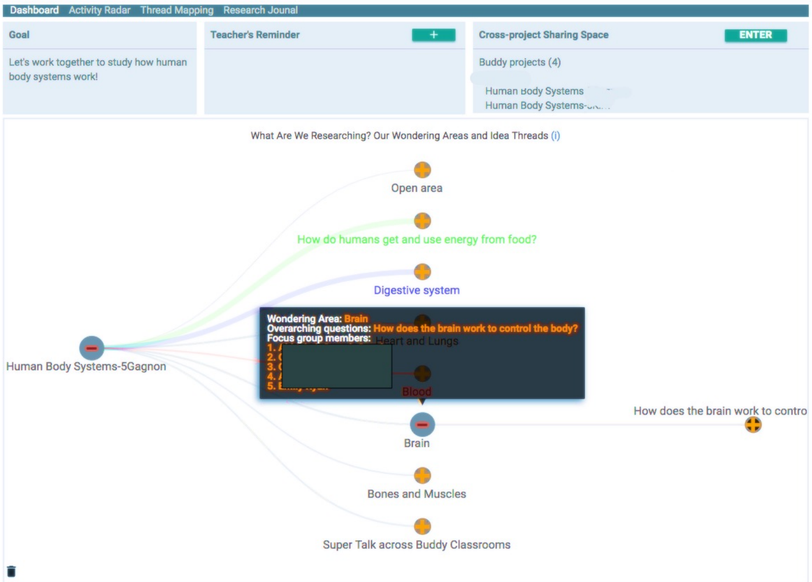

Figure 1. Project dashboard with a visual organizer of the collective wondering areas and idea threads. The thickness of each branch shows the intensity of online contributions in each area.

(b) Visualizing the conceptual, temporal and social profiles of each idea thread: Drawing upon the temporal inquiry-thread analysis developed in our prior work (Zhang et al., 2007), ITM organizes and visualizes students' online discourse in each idea thread as theme-based, temporal interactions. Each idea thread represents a conceptual line of inquiry that involves a sequence of discourse entries--possibly involving several build-on trees--investigating a shared inquiry object over a time period. Figure 2 shows the discourse in an idea thread developed by a group of fifth-graders focusing on how the brain works. The discourse entries (notes) and build-on responses are displayed in a two-dimension space based on the timeline of note creation and the authors involved, showing the temporal and social profile of student contributions in this line of work.

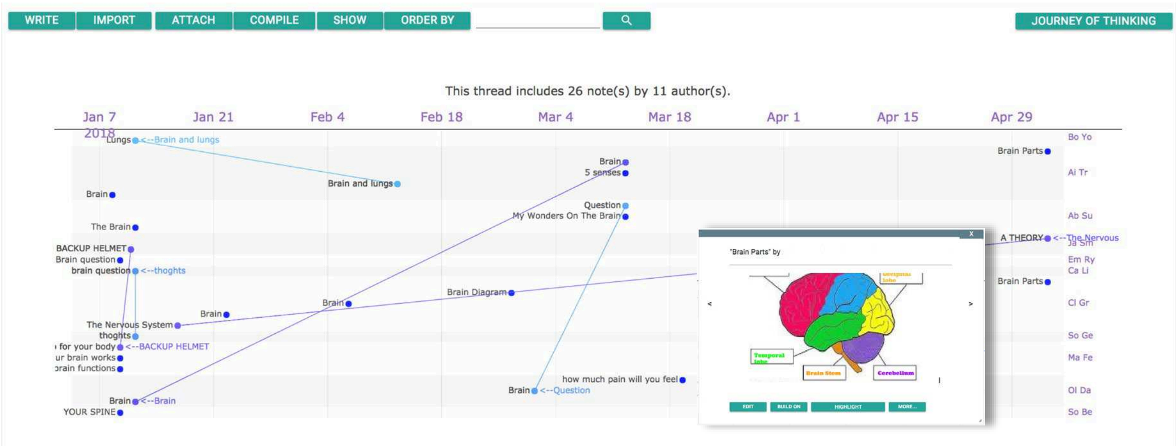

Figure 2. An idea thread developed by a Grade 5 classroom focusing on how the brain works. Each dot represents a note (click to open), and a line connecting two notes shows a build-on connection. The notes are displayed based on the time of creation (x-axis) and author (y-axis).

(c) Reflective documentation of Journey of Thinking in each thread of inquiry: As the conversation in each thread of inquiry proceeds giving rise to new insights as well as deeper issues, the contributors co-compose a Journey of Thinking (JoT) synthesis to deliberate their idea progress. JoT is a reflective "super note" that includes three sections: problems/issues explored, “big ideas” learned so far, and deeper research needed. Scaffolds are provided in each section to guide student reflection. For example, for the synthesis of the “big ideas” learned, students frame their ideas using “We used to think…now we understand…” (see Table 1).

Table 1: A Journey of Thinking written by a group of 5th graders in the idea thread about breathing

Questions explored:	[We want to understand:] how do the tissues use the oxygen? How and why do we breathe?
Big ideas learned:	[We used to think:] That there was not a big process to this. [We now understand:] We get oxygen from air we breath in. The oxygen goes through the thin walls of the air sacs. With the help of hemoglobin, oxygen passes through the air sacs into the blood vessels throughout the body. As that happens CO2 goes out of your body. …
Deeper research needed:	[We need to do more learning] about how air get around the body. [We need better theories about] Where is hemoglobin exactly located in the body and does it do anything else besides carry oxygen to the blood, and bring CO2 back into the lungs. [We need to further understand] …more about tissues.

(d) Mapping collective progress and connections across different threads of inquiry: At a higher level, the collective landscape of a whole knowledge building initiative is mapped out as clusters of idea threads that investigate interrelated issues through the contributions of all the members (Figure 3). The map of idea threads shows how the different threads of inquiry have evolved over time and further visualizes cross-thread connections, which show student efforts to build on and integrate ideas from the related areas to develop coherent understandings (see analysis in Zhang et al., 2018). The connections include (a) build-on links among the notes in the different idea threads; and (b) connective “bridging contributions,” each of which simultaneously investigates two or more topics focusing on the interrelated issues and cross-cutting ideas. For example, in Figure 3, there is a rich set of notes bridging thread #1 (heart and lungs), #3 (brain control), and #4 #4 (blood), as marked by the dashed vertical lines. Thus, with the visualizations and analytics embedded in the map of idea threads, students can reflect on the temporal process of their inquiry as well as their social participation (e.g. the number of notes and authors involved) and connectedness.

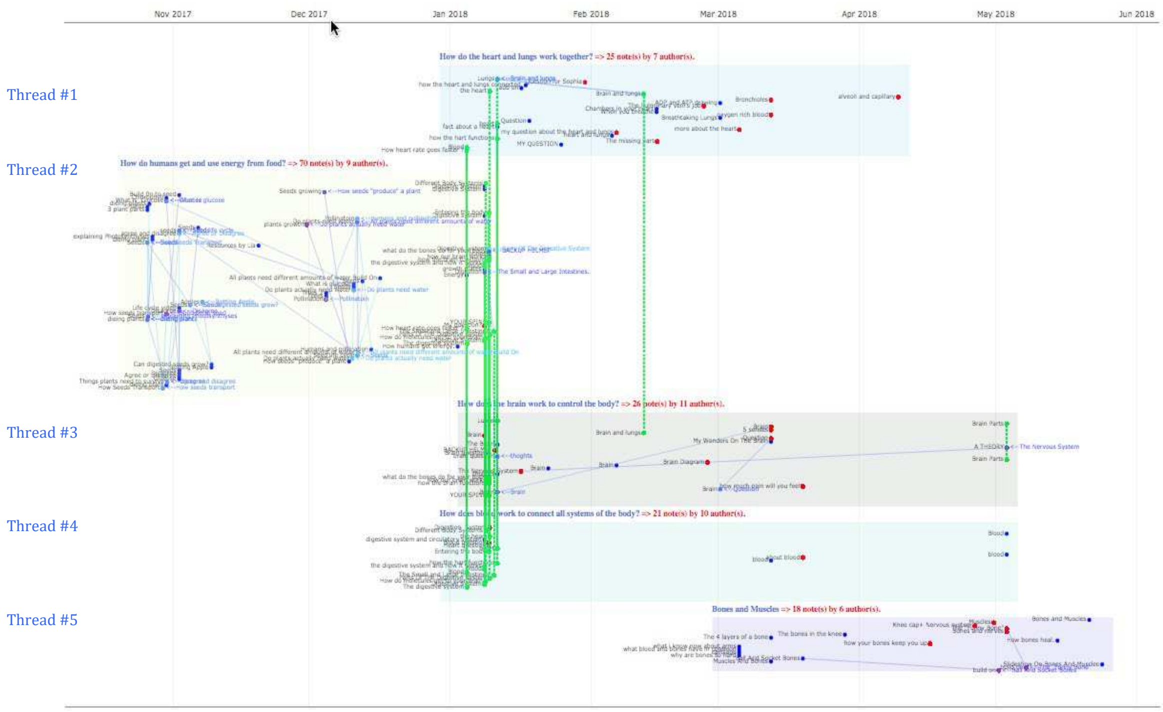

Figure 3. Mapping student discourse in the different idea threads developed in a Grade 5 classroom that studied the human body. Each color stripe represents an idea thread addressing a principal problem, spanning from the

earliest to the latest note created. Each dot shows a note. A line connecting two notes indicates a build-on connection. Dashed vertical lines mark the notes belonging to multiple threads bridging the different lines of discussions.

Principle 2: Boundary crossing between knowledge building communities

On the basis of the student-driven inquiry in each classroom community, ITM further incorporates supports for cross-community interaction, which is approached using a multi-level, boundary-crossing design (Zhang et al., 2017). As students engage in focused inquiry and conversations and make progress in their own classroom, they reflect on their progress of inquiry and generate JoT super notes, as synthetic knowledge artifacts. These artifacts are used as boundary objects (Star & Griesemer, 1989) to support higher-level interaction across classroom communities.

In the related literature, boundary objects are defined as artifacts (e.g. reports, tools, models) that can be used to bridge the boundaries (discontinuities) between different social worlds (Star & Griesemer, 1989). Objects from a community often have contextual meanings that are not easily accessible to other communities. What makes boundary objects effective for bridging different communities of practice is their interpretative flexibility as a "means of translation" (Star & Griesemer, 1989): they have a structure that is common enough to make them recognizable across the different social contexts and allow different communities to interact and work together. Through interacting with shared boundary objects, members from different communities can identify, understand, and reflect on their different practices, so they can develop better understandings and practices within their own community and potentially create new forms of practices at the intersection of the different communities (Akkerman & Bakker, 2011).

As noted previously, individual online discourse entries are hard to be used as boundary objects for cross-classroom sharing and interaction. Therefore, ITM uses high-level structural representations in the form of idea threads and JoT syntheses as boundary objects. These synthetic artifacts capture the journeys of inquiry taking place in different classrooms using a set of common scaffolds (see Table 1), so they can help the different communities to understand one another's inquiry directions and knowledge progress. Specifically, ITM incorporates a cross-classroom sharing space for each knowledge building initiative (See Figure 1). The teacher can create "buddy connections" with other classrooms that are studying the same or related content areas, which may come from the same or a different school site. Students can then interact with peers in the buddy classrooms in the follow ways:

(a) Ongoing access to the buddy classrooms' wondering areas and idea threads: Students can see what the buddy classrooms are researching based on their wondering areas and idea threads (see Figure 1), and compare the wondering questions pursued by the different communities. For deeper information, they can also directly view the online discourse in any of the idea threads (in a read-only mode).

(b) Ongoing sharing of the JoT syntheses: Students can access the syntheses generated by the buddy classrooms, and find the most relevant syntheses based on the keyword-based index or using the search tool. As noted previously (Table 1), each JoT synthesizes the progress in a thread of inquiry including the questions explored, "big ideas' learned, and deeper research needed. Thus, by viewing other classrooms' JoT syntheses, students can get a sense of their journey of inquiry and learn from their "big ideas" and deepening questions. For example, two upper elementary classrooms collaborated in their inquiry about human body systems. While both classrooms investigated how the heart works as part of their inquiry, one classroom's inquiry questions focused more how the healthy heart functions while the other classroom researched problems about how holes in the heart affect its function. Through reading the heart-related JoT of the other classroom, students realized the different questions asked and discussed the two perspectives to develop coherent understandings (Zhang et al., 2017).

(c) Live Super Talk across buddy classrooms: Students can propose challenging issues as potential topics for cross-classroom discussion, which is called "Super Talk." For example, in our research, four Grade 5 classrooms studying the human body worked as buddy classrooms. As students made progress in their own classroom understanding how the different body systems work, a few students in one of the classrooms were intrigued by the question of how the human body grows. They proposed this challenging issue as a Super Talk topic shared by the four classrooms. A total of 20 students from the four classrooms contributed 23 notes, looking into how people grow as related to the brain, spine, bones, muscles, skin, digestion, cells, and genetics.

Principe 3: Embedded analytics to leverage student reflection and idea interaction

ITM integrates a set of analytics and visualizations in the local discourse space and cross-community space (see elements of analytics in Figures 1-3). Specific analytics embedded in the online discourse spaces aim to foster students' reflective monitoring of the temporal, social, and conceptual profiles of their inquiry. A summary of the key analytical information is also reported in the Activity Radar, with which students can trace their personal and collective contributions to the various wondering areas and idea threads in a selected time period. Additionally, in collaboration with analytics researchers we tested a set of automated tools to help students monitor inquiry directions, personal contributions, and collaborative connections. For example, to help students monitor emerging topics/areas of inquiry and review progress, ITM provides an automated tool for topical modeling. Specifically, it uses an augmented Latent Dirichlet Allocation (LDA) (Blei, 2012) method to retrieve conceptual topics from student online discourse in relation to topical structures detected from the relevant expert texts (e.g. Wikipedia article). For each topic, the tool further recommends the most relevant online posts, ranked based on semantic relevancy. The user can then review the posts as potential entries for setting up a new idea thread, and define the topic name based on the top keywords. To support student review of each idea thread, ITM further incorporates automated analysis enabled by LightSIDE (formerly known as TagHelper — see Rosé et al., 2008). LightSIDE learns from human-coded discourse data to classify student online posts based on contributions types, including questioning, referencing sources, theorizing, and using evidence (see Tao & Zhang, 2018 for the coding scheme). The automated classification is used to help students monitor the various online discourse moves in each thread of inquiry in order to make informed improvement. To facilitate cross-community interaction, we further tested analytics to gauge the semantic similarity between the idea threads of different communities. Students can find relevant inquiry work conducted by other classrooms, with which they may develop buddy connection and collaboration.

Design-based research

ITM has been tested and refined through our multi-year design-based research conducted in a set of Grades 3-6 classrooms (Zhang et al, 2013, 2014, 2017, 2018; Zhang & Yuan, 2018). Students in each classroom investigated a science topic over multiple months with the support of ITM and Knowledge Forum. Their work integrated whole class knowledge building conversations, individual and group reading, experiments and observations, and so forth. Major questions, ideas, and findings generated through face-to-face activities were contributed online for continual discourse. With their teacher's support and using ITM, students engaged in metacognitive meetings to reflect on the emerging interests and ideas, form shared wondering areas and inquiry directions, and organize their collaborative roles to guide their work in the shared inquiry areas. The visualizations of the wondering areas and collaborative roles were used to guide their monitoring and planning of the ongoing participation and discourse. As the inquiry deepened within their own classroom community, students reviewed productive threads of ideas and composed JoT syntheses, which were shared with their buddy classrooms to stimulate cross-community interaction. Multiple sources of data were collected and analyzed including video records of metacognitive meetings in the classrooms, online discourse and JoT syntheses, individual reflective portfolios, and interviews with the teachers and students. We summarize the main findings below focusing on the within-community and cross-community processes.

Co-constructing shared inquiry structures serves to inform students' ongoing discourse and enhance student understandings

The data analysis documented the processes by which students worked with their teacher to co-construct shared inquiry structures to guide their collective work, including shared frames of collective wondering areas and idea thread topics, mapping of cross-thread connections, and ongoing syntheses of JoT. Such structures served to inform students' ongoing contribution and interaction. With ITM reflection, students were able to conduct more productive and connected discourse: there was a higher proportion of notes identifying deeper questions, using evidence to examine explanations, and integrating different ideas to address challenging issues. Their discourse also became more connected with more build-on links and more connective notes that investigated interconnected inquiry themes and issues (Zhang et al., 2013; 2014; 2018). The enhancement to student inquiry and discourse contributed to improving students' knowledge outcomes. Students with ITM achieved more sophisticated understandings of the science topics as measured based on the content analysis of their reflective portfolios (Zhang et al., 2018). Each student also developed clearer awareness of their community's knowledge goals and progress beyond their personal interests, conducive to enhancing personal learning and collaborative connections (Zhang et al., 2014).

Cross-classroom interaction leads to mutual learning and advancement

We further tested cross-classroom interaction for knowledge building (Zhang et al., 2017, 2018). For example, a design-based research study was conducted in two grades 5/6 classrooms that studied human body systems over a 10-week period (Zhang et al., 2017). As the students conducted focused inquiry and discourse within their own community, they reviewed productive threads of ideas and posted JoT syntheses in a cross-community space. The syntheses were written by students using ITM's scaffolds for JoT reflection: *Our problem, We used to think…and now we understand…, We need deeper research.* A set of syntheses from the previous classrooms studying human body systems was also posted in the cross-community space. The analyses of the classroom discussions and student interviews suggest that the students engaged in active and substantial interactions with the JoT syntheses from other classrooms. They identified relevant and interesting inquiry topics from other classrooms and compared the different perspectives and ideas, which triggered students' deep reflection on their own inquiry. Further iterations of this design-based research expanded the cross-classroom interaction to more classrooms studying human body systems (Zhang & Yuan, 2018). Content analysis showed that the students' JoT syntheses had a high quality of reflection in capturing solid knowledge progress and deep questions. Social network analysis indicated that through reading the JoT syntheses from their buddy classrooms, students built extensive peer connections focusing on their own inquiry areas as well as the broader scientific concepts. They further identified challenging topics (e.g. how people grow) at the intersection of their interests to conduct cross-classroom collaboration and discourse, putting together their knowledge about the specific body parts to develop coherent explanations.

Conclusions and implications

ITM and the related studies contribute new strategies to address the intra- and inter-community challenges of long-term knowledge building. Particularly, this research elaborates a reflective structuration approach to implementing long-term inquiry and knowledge building for educational transformation. In a knowledge building initiative (unit) that may extend over multiple weeks or months, the teacher can work with his/her students to co-structure their collective journey of inquiry over time without extensive pre-scripting of the inquiry directions and tasks. Through ITM-supported reflective processes, students can work with their teacher to co-structure the high-level issues about their inquiry, such as what to investigate, through what processes, by whom/with whom as their inquiry unfolds (Zhang et al., 2018; Tao & Zhang, 2018). ITM provides meta-layer representations and tools to capture the co-constructed directions and structures of inquiry, which are visualized to aid members' reflective monitoring and participation. The ITM-based research further elaborates a boundary crossing approach to cross-community interaction. While students engage in focused inquiry and discourse within their own classroom, they generate reflective Journey of Thinking syntheses, as boundary-crossing objects, and participate in the Super Talk to investigate challenging problems together. In sum, the ITM-based technology designs and classroom processes shed light on new designs of socio-technological infrastructures for enabling networks of knowledge building communities, each of which engage in continual idea advancement while building on the knowledge work of other communities. ITM's generic data exchange model supports data exchange with other online discourse environments besides Knowledge Forum. Building on the existing advances, we are currently designing analytics and feedback tools to help teachers and their students monitor emergent inquiry directions and progress in their classroom while discovering potential knowledge connection with other communities.

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