
Connecting Knowledge Spaces: Enabling Cross-Community Knowledge Building through Boundary Objects

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Practitioner Notes

What is already known about this topic

- Students work with a collective knowledge space where they contribute and interact with one another’s ideas to advance their community’s knowledge.
- Existing designs of collective knowledge spaces focus on supporting students’ interaction in individual classroom communities, which is often organized as relatively short inquiry activities lasting over a couple of weeks.

What this paper adds

- A multi-level emergent interaction design for connecting the knowledge spaces of different communities.
- Elaborated classroom processes and technology support for enabling knowledge building across classroom communities.

Implications for practice and/or policy

- Teachers can facilitate collaborative knowledge building in each classroom and further create cross-community connections for mutual learning and idea build-on.
- It is important to support student-driven efforts to develop interconnected knowledge spaces in order to enable sustained knowledge building and deep inquiry across classrooms.
**Abstract**

A learning community works with a collective knowledge space where members contribute and interact with one another’s ideas to advance their community’s knowledge. This study aims to explore designs of collective knowledge space to support cross-community interaction. A design experiment was conducted in four grade 5 classrooms with the support of Knowledge Forum over a school year. As students conducted focused inquiry and discourse within their own community, they reviewed productive threads of ideas and created “super notes” (idea thread syntheses) for cross-community sharing and interaction. A set of “super notes” from previous classrooms studying human body systems was also posted in the cross-community space. Qualitative analysis results showed that students wrote and posted “super notes” to capture substantive idea progress and deepening questions that had emerged from their inquiry. Social network analysis of who had read whose “super notes” revealed extensive social interactions between the four classrooms as well as among the students within each classroom. Analysis of the classroom conversations that followed the “super notes” reading elaborated how students built on the insights gained from the cross-classroom interactions to develop deeper understandings in their home classroom. Analyses of teacher interviews and observation data documented the teachers’ roles to contextualize the purpose of the cross-classroom space, support “super notes” reading and writing, and scaffold cross-classroom connection and conversation.
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Introduction

Research over the past two decades has produced deep insights into how students may work as learning communities to pursue joint inquiry and build disciplinary knowledge (Bielaczyc & Collins, 1999; Brown & Campione, 1996; Engle & Conant, 2002; Hod, Bielaczyc, & Ben-Zvi, 2018; Scardamalia & Bereiter, 2006). Various social technology platforms have been developed to support students’ collaborative inquiry, knowledge building, and discourse (Slotta, Suthers, & Roschelle, 2014). As an essential feature of learning communities, students work with a collective knowledge space where they contribute and interact with one another’s ideas to advance their community’s knowledge. Existing designs of collective knowledge spaces focus on supporting students’ interaction in individual classrooms, which is often organized as relatively short inquiry activities. Further research needs to extend students’ collaboration and inquiry to longer terms and higher social levels (Engle, 2006; Stahl, 2013) supported by new configurations of collective knowledge spaces. The study reported herein tested new designs of collective knowledge space to support cross-community interaction as part of a yearlong science inquiry.

Collective Knowledge Spaces for Knowledge Building

A learning community has a collective goal and shared a culture of learning, which focus on advancing the collective knowledge of the community in a way that also supports members’ individual learning and growth (Bielaczyc & Collins, 1999; Hod, Bielaczyc, & Ben-Zvi, 2018; Scardamalia & Bereiter, 1994). Different from individual knowledge represented as personal notions and mental models, collective knowledge is a social product with an out-in-the-world
existence (Bereiter, 2002), such as theories, designs, and narratives shared in various public spaces. In creative knowledge work, participants build on their community’s existing knowledge and make new contributions to advance the “state of the art.” (Scardamalia & Bereiter, 2006) However, in traditional classrooms, students rarely have the opportunity to advance collective knowledge. To overcome this barrier, researchers have created innovative platforms that provide student-centered, collaborative spaces where students’ ideas can take on a public life, being continually shared, built upon, reused, and revised (Scardamalia & Bereiter, 2006; Slotta, Suthers, & Roschelle, 2014; Zhang, Tao, Chen, Sun, Judson & Naqvi, 2018). Aligned changes in face-to-face classroom arrangements provide flexible spaces, time, and social configurations for student-driven collaboration and knowledge building (Zhang, Scardamalia, Reeve, & Messina, 2009).

The cyber and physical changes result in a new collective knowledge space, which is an important part of the socio-technological infrastructure (Bielaczyc, 2006) and learning spaces (Hod, 2017) that support learning communities. Collective knowledge space is not simply a place for sharing and storing information; rather it is a social landscape in which members interact with one another through the knowledge objects that they produce and use, and, thereby, transform their shared knowledge practices as well as the social relationships and identities of the members. In a broader context, philosopher Pierre Lévy (1997) identifies knowledge space as a new type of anthropological (human) space, which is defined as a system of proximity unique to the world of humanity. As cyber technology dramatically transforms the means and tools of knowledge production and communication, speeds up the process, and increases the number of people involved, knowledge space is becoming our civilization’s new horizon, which mediates and controls the proceeding forms of human spaces associated with territories, commodities, and
professions (Lévy, 1997). Thus, it is imperative that students learn to work with and contribute to collective knowledge space in preparation for their future lives and careers. Research on future learning spaces needs to include collective knowledge space as a critical element. Other physical and online elements of learning spaces may be connected with and mediated by collective knowledge space to create a dynamic flow (see Hod, 2017); student ideas generated in the various settings (e.g., studio, lab, classroom, online) can be contributed to their collective knowledge space for further investigation and continual improvement, vice versa.

Recent research has revealed new opportunities for students to access and contribute to collective knowledge space supported by new technology (Zhang, 2009). Such research is often grounded in the view of learning as knowledge-creation/knowledge building, which involves generating new understandings and tools and constructing/reconstructing new learning spaces (Bereiter, 2002; Ellis & Goodyear 2016; Paavola et al., 2004). A rich set of studies has been conducted in the context of knowledge building communities, a model of learning communities developed to engage students in knowledge-creating processes to advance the collective knowledge of their community (Scardamalia & Bereiter, 2006). The Knowledge Building processes are supported by Knowledge Forum, which provides an online knowledge space where students contribute diverse ideas and improve their ideas through interactive discourse. The online space is organized as different views (workspaces) each focusing on a knowledge goal or area. Students write notes, which may include multimedia elements, to contribute questions, ideas, and information sources, and build on and reference one another’s notes to engage in interactive discourse. In the online discourse, students not only share information but continually improve and transform their understandings while identifying deeper problems (van Aalst, 2006, 2009).
Existing studies on Knowledge Building and other models of learning communities focus almost exclusively on student collaboration in individual classrooms, with the online knowledge space set up for each community without cross-community idea flow. Even though the online systems can easily create a permanent record of student postings, the knowledge advances achieved in the discourse are not visible or easily interpretable for other communities. New online spaces and databases are typically created for each new student cohort in each new school year. The ideas developed by the previous students are archived but not reused. Further research needs to explore effective ways to connect the knowledge spaces of different communities.

**Extending and Connecting Knowledge Spaces through Boundary Crossing Design**

Among the few early explorations of cross-community interaction for knowledge building, Lai and Law (2006) reported a study conducted in two classrooms that engaged in collaborative knowledge building supported by Knowledge Forum. Students in each classroom had access to the online discussions of their partner classroom. Students benefited from seeing the different inquiry practices of their partner classroom (e.g., questioning), which helped them further improve their own inquiry and discourse. Another study conducted by Laferrière and colleagues (2012) tested cross-community sharing among students from three international sites. Each classroom gave other classrooms access to their online discourse space so they could read their notes and respond.

A challenge arises with the direct sharing of online discourse space across classrooms: students often find it difficult to understand the peer classrooms’ inquiry progress by reading their interactive online postings without knowing the context of the classroom work. Therefore, the current research explores improved strategies to connect the knowledge spaces of different communities using a multi-level emergent interaction design (Zhang, Bogouslavsky & Yuan,
2017). This approach to collective knowledge space design has three interrelated design elements that support dynamic idea interaction across social levels. First, the collective knowledge space is configured as multiple extensible layers to support student interaction within their local community space as well as higher levels of interaction in a cross-community space. While students in each classroom engage in focused inquiry and ongoing discourse in their local and protected knowledge space, they reflect on the major insights and “big ideas” that have emerged from their ongoing inquiry and generate meaningful knowledge artifacts that can be shared with other classroom communities.

As the second element, there are temporal emergent dynamics aligned with the social interaction across the social levels. The temporal emergent dynamics include bottom-up emergence and top-down influence, which unfold over time to drive the dynamic changes in complex social systems (Sawyer, 2005; Lemke, 2002). On the one hand, students’ ongoing inquiry and interactive discourse in their own community’s space give emergence to the major inquiry directions and advances that are worthwhile to share in the cross-community space. On the other hand, through participating in the cross-community sharing and discourse, students learn special ideas from peers and develop cross-cutting concepts that can be brought back to their own classroom to enrich and expand their local discourse and inquiry, which may lead to further emergence of deeper insights that may be shared with other communities.

As the third element, student interaction in the cross-community space is mediated through “boundary objects.” Boundaries exist between different social spaces (social worlds). Boundary objects are artifacts (e.g., reports, tools, models) that can be used to bridge the boundaries and gaps between the different social worlds (Star & Griesemer, 1989) for potential mutual learning and innovation. Wenger (1998) defines them as “forms of reification around
which communities of practice can organize their interconnections.” (p. 105) Regular objects formed in a community often have contextual meanings not 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 worlds and allow different communities to interact and work together. As noted above, students’ raw online posts are difficult to be used as boundary objects to bridge different classroom communities. Therefore, in this study, students generate synthetic boundary objects for cross-community sharing on the basis of the extended knowledge building discourse within their own community. The synthetic boundary objects take the form of idea thread syntheses framed using shared structures of inquiry. As progress is made in their inquiry, students working on the various areas of inquiry selectively review and synthesize fruitful ideas that have emerged from their discourse. The selective reviews and syntheses of inquiry threads can facilitate peer learning and build-on across inquiry topics within each classroom; they may further be shared as boundary objects to enable cross-community interaction. Students from another classroom (or a subsequent student cohort) can use the syntheses of idea threads to view into the discussions and understand the extended journey and progress of the inquiry.

To support students’ reflective review and structuring of distributed online discourse, our team developed Idea Thread Mapper (ITM) (Zhang et al., 2018). ITM interoperates with Knowledge Forum (Scardamalia & Bereiter, 2006) and potentially other platforms that support online knowledge building discourse. Using ITM, students identify focal objects of inquiry addressed by their collective discourse and select important discourse contributions related to each focus. The discourse entries with a shared focus are displayed on a timeline, as an idea
thread, extending from the first to the last entry. Each idea thread has a “Journey of Thinking” synthesis. Students review their idea progress in the thread and co-author/update the “Journey of Thinking” synthesis. In line with the focus of knowledge building on continual idea improvement through progressive problem solving (Scardamalia & Bereiter, 2006), we designed a set of scaffolds for Journey of Thinking synthesis, including (a) overarching topic and problems, (b) we used to think…now we understand… and (c) deeper research needed. ITM has been used by a set of classrooms that studied various science topics, with a rich set of idea threads and Journey of Thinking syntheses archived. We have been conducting a multi-year design-based research to examine the processes and impacts of cross-community knowledge building mediated through idea thread syntheses, as synthetic boundary objects (Zhang et al., 2017). A design challenge that remains to be addressed is to better approach the idea flow between within- and cross-community interaction and extend the interaction to a larger social and time scale.

This article presents the second iteration of this design-based research, which was implemented in a set of four classrooms that engaged in a yearlong science inquiry. Instead of organizing the cross-classroom interaction near the end of the inquiry, the four classrooms worked on the cross-community space early on in the inquiry process for continual interaction. Specifically, this study investigates three research questions: (a) How did the students generate “super notes” to reflect on their inquiry progress for cross-community sharing? (b) How did the students from the four classrooms interact through the “super notes” for knowledge building? And (c) what role did the teachers play in facilitating the cross-community interaction? By addressing these questions, this study attempts to understand the emergent idea flow from the local to the cross-classroom space (question a), examine the cross-classroom interaction and its
influence on the knowledge work of each classroom (question b), and provide practical guidance on how to facilitate cross-classroom knowledge building (question c).

Methods

Classroom Contexts

This design experiment (Collins et al., 2004) tested cross-community interaction among four grade 5 classrooms that had a total of 93 students (10-to-11-year-olds) from a public elementary school located in the Northeast U.S. The four participating classrooms were located in the fifth-grade wing of their school building. Each classroom had its own schedule for science and other classes. The students studied human body systems from September 2016 to April 2017. Their inquiry was designed in line with the principles of knowledge building and supported using Knowledge Forum (Scardamalia & Bereiter, 2006). The four classrooms were taught by two teachers: Mrs. G and Mrs. K, each teaching science in two classrooms. Both teachers had two years of prior experience working with Knowledge Building pedagogy and Knowledge Forum.

The human body inquiry was kicked off with a set of hands-on activities that required students to use their body to achieve various challenging demands. Students in each classroom then generated various interests and questions and formulated shared wondering areas (e.g. why and how do we breathe?), which became the shared focus for students’ subsequent inquiry. Specifically, students generated initial ideas and improved their ideas by conducting research using reference materials, online resources, and science models. They participated in reflective knowledge-building conversations—“metacognitive meetings”—to share and co-develop their thinking while identifying what they needed to further research. Major questions, ideas, and findings generated through these classroom-based activities were contributed to Knowledge Forum for continual knowledge building discourse online.
The Design of the Local and Cross-Classroom Knowledge Space

The online space in Knowledge Forum was organized in line with the aforementioned multi-layer emergence approach to collective knowledge space design. As the local space, each classroom started with a home view, where students posted their questions and ideas and built on one another’s notes. As the inquiry and discourse unfolded, each classroom identified high-interest wondering areas related to the various body systems and functions. New views were created in Knowledge Forum corresponding to the new wondering areas identified (e.g. bones and muscles, brain, heart and lungs, cells). These areas were also listed on a big chart paper hanging on the classroom wall to guide student attention. Students formed into flexible groups to conduct the inquiry in the various areas, often sitting at the same desk in the classroom. Over time they posted their ideas and findings in the related views and participated in interactive discourse online to deepen their understandings (Figure 1).

![Figure 1. A Knowledge Forum view about cells. Each square shows a note. Each link between two notes indicates a build-on connection.](image)

To support cross-community interaction, a cross-classroom “Super View” was created on Knowledge Forum for students to post idea thread syntheses called “super notes.” (Figure 2) The
Super View space was first populated with a collection of “super notes” created by a prior cohort of students from the same school and a group of students from a different school who also studied the human body using Knowledge Forum in the previous school year. The “super notes” were organized based on body systems and functions. With inquiry progress made in the first eight weeks, students were introduced to the Super View around mid-November. They selectively read the “super notes” from the previous student cohort as a resource to support their inquiry.

Figure 2. The Super View for cross-community interaction. On the left is a set of super notes created by the prior cohort group of students studying the same science topic, arranged based on the different human body systems. On the right is the cross-classroom sharing space for the four current classrooms framed using four puzzle pieces.

As students made progress in understanding the various human body systems and functions, they worked with their peers who had similar interests to review their journey of thinking and co-author “super notes” to synthesize their idea progress for cross-classroom
sharing. Each “super note” was organized using the Journey of Thinking scaffolds (sentence starters) of Idea Thread Mapper, which interoperates with Knowledge Forum. A total of 56 “super notes” were generated by the four classrooms (see Figure 3 for an example). Extending the online sharing and interaction, members in each classroom discussed what they had learned from the other classrooms, identified connections, and built on the information gained to develop deeper understandings.

Figure 3. An example “super note” that synthesizes students’ journey of thinking about how the brain works.

Data Sources and Analyses

Table 1 summarizes the data sources and analyses used to answer each of the three research questions.

Table 1

Data Sources and Analyses to Address the Research Questions
Research question | Data sources and analyses
--- | ---
(a) How did the students generate “super note” to reflect on inquiry progress? | - temporal tracing of student creation of “super notes” based on classroom observations; 
- content analysis of the “super notes.”
(b) How did the students interact across classrooms through the “super notes”? | - social network analysis of who had read whose “super notes;” 
- qualitative analysis of the classroom discourse following the “super notes” sharing; 
(c) What role did the teachers play? | - qualitative analysis of the teacher interviews; 
- video analysis of classroom discussions.

To answer the first research question, we conducted classroom observations to trace the temporal process by which students in the four classrooms generated “super notes” to synthesize their inquiry progress. To further examine the quality of students’ “super notes” writing, we conducted content analysis (Chi, 1997) of the “super notes” focusing on the problems/questions and ideas synthesized. Drawing upon the coding scheme tested in the related studies (e.g. Tao & Zhang, 2018; Zhang et al., 2007), the content analysis coded (a) the inquiry topic of each “super note;” (b) the types of inquiry questions including broad questions about the body systems versus deeper, more specific questions to elaborate the structures, functions, reasons/mechanisms, conditions and connections; and (c) the quality of the understandings synthesized in the “super notes” gauged based on scientific sophistication (1-pre-scientific, 2-hybrid mixing scientific information with intuitive understandings, 3-basically scientific, and 4-scientific) and epistemic complexity (1-unelaborated facts, 2-elaborated facts, 3-unelaborated explanations, and 4-elaborated explanations). Two researchers coded all 56 “super notes” independently, and then compared the results, resulting in an inter-rater agreement of 93%.

To address the second research question, we conducted social network analysis to examine who had read whose “super notes” among the four classrooms using the software tool of UCINET (Borgatti et al., 2002). We further observed and analyzed the classroom discussions in
which students referred to what they had learned from the “super notes” to build idea connections and seek deeper understandings.

To examine the teacher’s role in facilitating cross-classroom interaction, we conducted a semi-structured interview with each of the two teachers. Each interview lasted for approximately 30 minutes. The interview questions prompted the teachers to reflect on how they facilitated their students’ knowledge building as a whole and cross-classroom interaction in particular. For example, a question asked: “You made efforts to enable cross-community connection, such as through the Super View. What did you specifically do to facilitate student reading and writing of Super Notes?” The teacher interviews were analyzed using a grounded theory approach (Strauss & Corbin, 1998). The first author read and re-read the transcriptions, created open codes, which were then refined and clustered into three primary themes. The themes were further validated through checking data against the themes and triangulating the identified themes across the data sources.

Results

How did the students generate “super notes” to reflect on inquiry progress for cross-community sharing?
We first traced the temporal process by which the four classrooms generated the “super notes” \((n = 56)\) to reflect on their knowledge progress as their work proceeded. Figure 4 shows the number of “super notes” posted by each classroom in the different months from November to April, spreading across the different phases of the human body inquiry.

![Diagram of Super Notes by Classroom over Time]

Figure 4. The number of “super notes” created by classroom K, M, G, and W over time. We further analyzed the content alignment between students’ “super notes” and their regular online discourse in their local views.

Each “super note” was coded based on its content topic related to the different human body systems. The same coding was implemented for each of the regular notes created by the four classrooms. Figure 5 reports the topic distribution of the “super notes” and Figure 6 shows the topic distribution of students’ regular note written in their local online discourse.
As Figure 5 and 6 suggest, the “super notes” from the four classrooms documented inquiry progress in shared topical areas as well as areas somehow unique to the different classrooms. As a general pattern, students posted more “super notes” in the areas that had been most intensively discussed in the local discourse space. At the same time, students also posted super notes about a few specialized topics that did not have heavy discussions in their classroom. They considered these topics as interesting and potentially helpful for other students.
To gauge the quality of student reflection on their journey of thinking documented in the “super notes,” we coded student ideas summarized in the “super notes” under “We used to think” and “Now we understand” based on two dimensions: scientific sophistication and epistemic complexity (see Zhang et al., 2007). The coding categories and results are reported in Table 2. In terms of scientific quality, students’ prior ideas identified under “We used to think” are mostly pre-scientific misconceptions (38%) or hybrid ideas mixing scientific information with misconceptions (48%), while their updated ideas summarized under “Now we understand” are scientific or basically scientific. Compared to their prior ideas, the updated ideas also show higher levels of complexity, mostly presenting elaborated explanations or elaborated facts. These results show that the students were able to reflect on substantive inquiry progress and synthesize complex scientific ideas for cross-classroom sharing.

Table 2

<table>
<thead>
<tr>
<th>Coding dimension and category</th>
<th>We used to think</th>
<th>Now we understand</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scientific Sophistication</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-Pre-scientific</td>
<td>38%</td>
<td>0%</td>
</tr>
<tr>
<td>2-Hybrid</td>
<td>48%</td>
<td>0%</td>
</tr>
<tr>
<td>3-Basically scientific</td>
<td>14%</td>
<td>18%</td>
</tr>
<tr>
<td>4-Scientific</td>
<td>0%</td>
<td>82%</td>
</tr>
<tr>
<td><strong>Epistemic Complexity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-Unelaborated Facts</td>
<td>95%</td>
<td>9%</td>
</tr>
<tr>
<td>2-Elaborated Facts</td>
<td>0%</td>
<td>32%</td>
</tr>
<tr>
<td>3-Unelaborated Explanations</td>
<td>5%</td>
<td>9%</td>
</tr>
<tr>
<td>4-Elaborated Explanations</td>
<td>0%</td>
<td>48%</td>
</tr>
</tbody>
</table>

We further coded students’ reflection on their inquiry questions highlighted in the “super notes” including questions explored so far (“Our research topic and problems”) and deeper questions. The coding categories and results for this analysis are reported in Table 3, showing a
wide range of questions asked by students. Questions identified for deeper research focused on more specific issues seeking elaborations of reasons and mechanisms.

Table 3.

<table>
<thead>
<tr>
<th>Coding of Questions in “Super Notes,” Including Questions Explored and Those for Further Research.</th>
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</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Question explored</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Total questions</td>
</tr>
<tr>
<td>Broad questions</td>
</tr>
<tr>
<td>Specific questions</td>
</tr>
<tr>
<td>Substance/Definition</td>
</tr>
<tr>
<td>Characteristics</td>
</tr>
<tr>
<td>Function</td>
</tr>
<tr>
<td>Reason/explication</td>
</tr>
<tr>
<td>Relation Connection</td>
</tr>
<tr>
<td>Conditions and Consequences</td>
</tr>
</tbody>
</table>

How did the students from the four classrooms interact through the “super notes” for knowledge building?

Social network analysis was used to examine who had read whose “super notes” among the students from the four classrooms. Figure 7 shows the extensive social connections formed among the students through the mutual reading of “super notes,” including reading the “super notes” created by peers from other classrooms and those from their own classroom. The densities of the reading interaction within each home classroom are slightly higher than those of cross-classroom interaction. We calculated the homophily measure E-I index to gauge the relative density of internal connections within a social group compared to the number of links that the group has to the external groups, ranging from -1 (all ties are internal) to 1 (all ties are external) (Krackhardt & Stern, 1988). E-I index = .08, showing a balance between within- and cross-classroom interactions.
In the Super View, students also read some of the “super notes” from the previous school year. We used the principal component network analysis to examine student reading of “super notes” from the same school year vs. from the prior students. As Figure 8 shows, the reading interactions among the current students were much more extensive than reading the “super notes” from the previous year, E-I index = -0.50 (in the range from -1 to 1).

Figure 7. Social network analysis of who had read whose “super notes” among the students from the four classrooms. Each node denotes a student. A line linking two students shows a social tie created through the reading.
Students in each classroom continued to conduct a deeper inquiry and participated in metacognitive meetings to discuss their understandings and challenging issues. In several of the classroom meetings, students reflected on their own inquiry in connection with the new insights gained from other classrooms and developed deeper understandings. For instance, Student A from classroom G, who was studying the heart and nutrition, read a “super note” from the previous student cohort class about the digestive system. She made an idea connection to address her research question, and shared her insights at a classroom meeting.

[11] T (Teacher G): Where has your research taken you?
[12] A (Student): Actually B(Student) is also doing it with me, first I went to heart, then I got more into potassium.
[13] T: You got off the heart branch?
[14] A: I am in the digestive system, but kind of in the middle of that, and just know like potassium.
[15] T: So why is it you are hovering between heart and digestion? There is a twig, the potassium?

[16] A: Yes, me and B (Student) were just wondering what potassium does to the heart, so then we thought how does it get to the heart? And our big question for a couple of weeks was how does it get into the bloodstream. So we know you can get it from citrus fruits, we knew that you eat it, and it goes down your esophagus, and then it gets to your stomach, and goes to the digestive system. But what we didn’t know…from the “super notes,” we’ve read one and know that there are little flaps in your intestines for nutrients to go into the bloodstream, so we found out that’s how it [potassium] gets into the bloodstream and the circulation takes it to the heart, and that's how your heart gets potassium.

[17] L(Student): That kind of helps me because I read something about the digestive system. I was wondering how the blood got nutrients, I was researching about it. So A (Student) just kind of gave me the answer, because the nutrients probably go into the bloodstream, so from there, the blood picks it up.

In the above discussion, student A first shared her journey of inquiry about the heart and digestion in collaboration with a peer, which had led them to the question of how nutrients like potassium that are important to the heart actually get to the heart. They then read a “super note” (from the prior school year) about how the small intestine absorbs nutrients. Building on the information gained, student A and B developed the understanding of how potassium enters the bloodstream and gets to the heart. Student L further followed up to share a related thought about how nutrients probably go into the bloodstream in general.

The teacher’s role in facilitating cross-community interaction

The teachers’ role was investigated through the qualitative analysis of the classroom video records cross-validated by the teacher interviews. To co-design the cross-community interaction, the teachers met with the researchers to review the procedures used in our first iteration (at a different school) and revised the process for their context. As the human body inquiry unfolded, they observed their students’ work in each classroom to monitor student individual progress and emerging shared areas of inquiry. They then introduced the Super View to each of their
classrooms and explained the purpose of this view for cross-classroom sharing and collaboration as a broader space connecting the four classrooms. They selected relevant “super notes” from the previous years’ classes as examples to show what “super notes” looked like. Students were encouraged to read the “super notes” from the previous and the current peer classes, and to reflect on their own knowledge and identify the knowledge connection and gaps in the broader picture of human body systems. Both teachers encouraged students to make purposeful and reflective decisions, including selecting the “super notes” that they should read as relevant to their needs and interests and deciding when they were ready to write a “super note” based on their progress. Both teachers made efforts to provide the time and space needed for students to pursue deep inquiry in each classroom while reflecting on their inquiry progress and connections.

In the interview, both teachers emphasized their role in developing students’ reflective awareness of the value of their own deep inquiry in the context of cross-classroom sharing, which gave rise to the excitement to share their knowledge with the other classrooms. Knowing that their “super notes” would be read by the broader peers from the peer classrooms, students felt motivated to conduct deep inquiry and create high-quality knowledge syntheses, and recognized the value of such work that could impact more people and benefit their learning. Reading "super notes" from other classroom gave students a sense of connection with other learners. It was helpful to clear up some of the students’ misconceptions, and to open their eyes to broader topics and deeper questions, which might be incorporated in their own inquiry and discussion.

The teachers also reflected on some of the challenges. A teacher commented that writing “super notes” required a high-level self-directedness among students so they could engage in meaningful reflection and mutual learning. The teachers suggested that the cross-classroom
sharing should start earlier in the learning process and take place on an ongoing basis for more extensive idea interactions.

**Discussion**

This study set out to explore new designs of collective knowledge space to support knowledge building across communities. The collective knowledge space was approached as a multi-level system, including the local knowledge space for each community to pursue focused and deep inquiry and a cross-community knowledge space where students interacted with a broader network of peers and boundary-crossing knowledge objects. The boundary-crossing knowledge objects took the form of “super notes”, each of which synthesized a line of inquiry using a common set of scaffolds. To understand the emergent idea flow from the local to the cross-community knowledge space, our first research question examined students’ generation of “super notes” based on their inquiry progress. The analysis of the temporal profile (see Figure 4) and topic distribution (Figure 5) suggests that students generated the “super notes” through a spontaneous, emergent process, which unfolded as students deepened their understandings in the various inquiry areas and reflected on their knowledge progress. The focused inquiry and discursive interaction in each classroom’s local space gave rise to “big ideas” that were perceived as worthwhile for sharing with other classrooms. As a result, students generated more “super notes” in areas that had more extensive discourse within their own classroom, even though there were also a few “super notes” synthesizing specialized inquiry of unique issues (Figure 5 and 6). With the scaffolds for reflecting on their journey of thinking, students’ “super notes” documented their high-quality reflection on their inquiry progress, which captured their advances in building complex scientific ideas (Table 2) while identifying deeper questions for further inquiry (Table 3). Reflecting on the challenges and gaps of knowledge in their
community’s inquiry also motivated students to read the “super notes” of their peer classrooms and search for insights that may help address their knowledge gaps.

Our analyses of the second research question looked into patterns of cross-community interaction and its influence on the deepening work in each classroom’s local space. Through reading one another’s “super notes,” students formed extensive connections with peers from the other classrooms as well as deeper connections with peers from their own classroom (see Figure 7). As part of the cross-community interaction, students also read some of the “super notes” generated by the previous student cohort studying the same science topic. Understandably, more active connections were built among the students from the current four classrooms than with those of the prior school year (Figure 8), possibly due to social familiarity and proximity. The analysis of the classroom conversations (metacognitive meeting) further revealed specific patterns by which students reflected on what they had learned from the cross-community knowledge space and built deeper conceptual connections to understanding how the human body systems work together. The insights gained from the cross-community space were further cycled back to each classroom to develop deeper understandings and inspire deeper collaboration and inquiry. For example, students in classroom G incorporated knowledge gained from a “super note” about how the small intestine absorbs nutrients to deepen their own inquiry about how the heart gets potassium that it needs.

The analysis of the third research question elaborated the teachers’ role in facilitating the cross-boundary interactions. As the teacher interviews and classroom videos revealed, the teachers played a number of crucial roles, including (a) contextualizing the Super View as a cross-community knowledge space and developing a shared sense of the purpose and structure of the “super notes,” (b) supporting student reading and creation of “super notes” by scaffolding
deep inquiry and reflection and monitoring the progress of each classroom to identify areas of inquiry with productive knowledge advances, and (c) facilitating cross-classroom interactions and the related extended conversations within each classroom to reflect on the insights, build connections, and put the knowledge together to explain difficult issues.

**Conclusions and Implications**

Taken as a whole, the results of this study provided an elaborated account of how young students could interact across the boundaries of the different classroom communities to engage in collaborative knowledge building. While existing studies on cross-community collaboration relied on the direct, single-layer sharing of collective knowledge space between different classrooms, this study tested a multi-layer emergent interaction design, which included local online spaces (Knowledge Forum views) for each community and a “super view” that served as the cross-community knowledge space. Within their local knowledge space, students in each of the four classrooms engaged in focused inquiry and ongoing discourse to advance their understandings of the various human body systems while identifying deeper issues for further inquiry. Over time, they monitored the major insights emerging from their ongoing discourse and inquiry and created “super notes” to document their journey of thinking using a set of scaffolds. The “super notes” were shared in the cross-community space, serving as boundary objects through which students from different classrooms came to interact with one another’s knowledge and inquiry work. The analysis showed that the “super notes” presented students’ high-quality reflection on the “big ideas” learned and deepening questions that had emerged from their journey of inquiry. Reading “super notes” led to extensive social contacts among the students from the four classrooms. The conceptual insights and questions accumulated in the cross-community space were further circled back to each classroom to help enrich its local discourse.
and develop deeper understandings. Both the local and the cross-community knowledge space are co-constructed and re-constructed (Ellis & Goodyear 2016) over time as students’ inquiry continually evolves to address new and deeper issues and build connections.

The results have several implications for conceptualizing and designing learning space for sustained knowledge building across communities. First, it is important to approach collective knowledge space as an essential component of learning space design for learning communities. Collective knowledge space rises above other physical aspects of learning space, with ideas generated in various physical activity settings selectively objectified as knowledge artifacts living in the collective knowledge spaces as the focus of continual discourse and cognitive interactions. Second, the results of this study further demonstrate the possibility to extend the design of collective knowledge space to include a cross-community layer that rises above each community’s local knowledge space. The local knowledge space of each community supports students’ ongoing inquiry and micro-level idea interaction on a daily basis; while the cross-community knowledge space supports higher, macro-level interactions focusing on major progress worthwhile for sharing with other communities. The knowledge progress can be shared through creating synthetic artifacts (“super notes”) that document the journey of thinking, as boundary objects to leverage students’ mutual learning and idea contact across communities. Working with the cross-community knowledge space over and above their local space gives students an expanded social context of knowledge building, which is similar to how real-world knowledge creators work across teams and locations to advance the knowledge of their fields. Students value the opportunity to contribute knowledge that can impact the broad peers and, at the same time learn from the broader inquiry progress to develop complex understandings.
Drawing upon the findings, our team recently upgraded Idea Thread Mapper to incorporate a cross-classroom sharing space where students can interact with peers from a set of “buddy classrooms” that study the related topics or challenges. Visualizations and semantic analytics are embedded in online knowledge space to help students monitor idea progress and build connections. With the upgraded technology, we are conducting further research to explore improved designs of cross-community interaction, which will contribute to sustaining long-term collaborative knowledge building at higher social levels for educational transformation.

**Statement on Open Data, Ethics, and Conflicts of Interest**

Due to ethical concerns and confidentiality agreements, the data of this study cannot be made openly available. A request to access the detailed coding procedures and data samples can be directed to the authors. This study was conducted in compliance with the research protocol approved by the University at Albany IRB (IRB #14-E-140). The authors have no conflicts of interest in the work reported in this study.

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