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Reflective Structuration of Knowledge Building Practices in Grade 5 Science Classrooms

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Abstract: This two-phase exploratory sequential design contributes to a dynamic approach to inquiry-based knowledge practices, reflective structuration, aiming to understand how student agency-driven science practices can become socially organized and supported in classrooms. The first phase of this research consists of two exploratory case studies conducted in two classrooms in school year 2013-2014 and 2014-2015 taught by teacher A to understand how students and teacher A co-constructed shared structures about what the community should investigated and how they should do inquiry. The second phase is a two-year design-based implementation research conducted in another two classrooms taught by teacher B in two successive school years (2014-2015 and 20152016), with knowledge building practices in classroom A as a baseline for comparison and detailed analyses of classroom B for design implementation. Qualitative and quantitative analysis of rich classroom data and online discourse showed how the shared structured were co-constructed and how reflective structuration helped to sustain and deepen the inquiry classroom B over time. These results, together with findings from our previous study, shed light on agency-driven reflective structuration as a self-sustaining mechanism to guide and sustain principle-based knowledge building practices without extensive pre-scripting.

Introduction

Advances about the nature of science and how people learn have re-conceptualized science education in the 21st century. As reflected in recent policy documents (NRC, 2012; NGSS Lead States, 2013), an evident shift has been made from acquiring scientific methods and conducting science inquiry to engage students in authentic science practices. Science practice, as a special type of social practices, keeps evolving over time through purposeful interactions among participants, constitute performances, science knowledge, and natural contexts while remains coherent to make progress in knowledge based on continuous evaluation and critique of emergent problematic situations (Ford, 2015; Rouse, 2007). Hakkarainen (2009) calls this type of social practice as knowledge practice, which aims at solving emergent problems and constant pursuit of novelty and innovation. Recent research has also highlighted the dynamic, creative, and improvisational aspects of knowledge practices beyond conventional notions of social practices as repetitive routines (Author et al., 2009; Engeström, 2008; Sawyer, 2007; Williams & Yang, 1999). To engage students in authentic science practices instead of mimic practices prepared by their teacher, students are supposed to be positioned as epistemic agents, who have the power to shape and reshape the construction of knowledge and practices of a community (Stroupe, 2014).A critical challenge to implement NGSS- aligned science learning is to understand how student agency-driven science practices can become socially organized and supported in classrooms.

Situated in the context of Knowledge Building pedagogy, this research contributes to a reflective structuration approach of science practices in which students are positioned as epistemic agents by co-constructing shared structures of inquiry with their teachers (Author et al., 2018). Specifically, this research seeks to achieve the following goals: 1) to explore different shared structures that students and their teachers co-generated to guide and sustain their knowledge building practices; 2) to understand how shared structures evolved from students' knowledge building actions over time and how students used the co-generated structures to further guide their actions; 3) to investigate the implementation processes of the reflective structuration framework in a knowledge building community over a whole school year; and 4) to examine the impact of the reflective structuration framework in supporting sustained and productive knowledge building practices.

Conceptual Framework

Any attempts to change the power and authority dynamics to make room for agency is bound to be linked to the structure that enable and constrain tangible actions (Giddens, 1979; Varelas, Settlage, & Mensah, 2015). In authentic knowledge-creating practices, knowledge workers do not simply enact repeated procedures to accomplish given tasks but continually create and adapt their social practices as their knowledge is advanced (Author et al., 2009; Knorr-Cetina, 2001). According to sociologists, emergent practices sustain over time largely through the formation and adaptive use of social structures (Archer, 1982; Giddens, 1984; Sewell, 1992). These social structures emerge and adapt to guide participants' actions and interactions, in terms of what participants needs to investigate, who should work on what in connection with whom, how they should conduct research and collaborate, as well as why their knowledge creating community should operate in certain ways (Author et al., 2018). However, in traditional science classrooms, these structures are usually supplied by the teacher through setting up the focus and problems of inquiry for students, putting students to fixed groups based on their physical locations in the classroom, providing specific steps or guidelines, and introducing certain rules, norms, and principles for students to follow. To grant students epistemic agency, it's necessary to break the inherent power structure in most classrooms, which places an emphasis on the teacher as the sole authority (Miller et al., 2018).

Reconciling the tension between student agency and structures, we identified *reflective structuration* as a self-sustaining mechanism through rich analyses of productive knowledge building communities (Author et al., 2018). In a nutshell, reflective structuration of knowledge practices refers to the reflective processes by which members of a knowledge building community co-construct, use, and adapt shared inquiry structures over time to channel their individual and collaborative actions as a dynamic social system. The co-constructed inquiry structures function as what sociologists call social structures: schemas of social actions that are reified with various resources to sustain the enactment, reproduction and transformation of social practices (Archer, 1982; Giddens, 1984; Sewell, 1992). These structures of inquiry can be used to inform and guide students' ongoing knowledge building actions and interactions, which, over time, may give rise to further elaboration and adaptation of inquiry structures.

Methodology

Research design and context

The research goals are achieved through a two-phase exploratory sequential design (Creswell & Plano Clark, 2011) conducted in four Grade 5 science classrooms across three school years. The first phase of this research consists of two exploratory case studies conducted in two classrooms in school year 2013-2014 and 2014-2015 taught by Teacher A, who had more than 10 years' experience in teaching Grade 5 science. These two cases explore: (1) how did a knowledge building community co-construct shared frames about what the community should investigate in the form of a list of "wondering areas"; and (2) how did a knowledge building community co-construct shared frames about how the community should conduct research represented as "research cycles". In the summer of 2013, our research team introduced the Knowledge Building pedagogy to the two Grade 5 teachers (teacher A and B) through a three-day workshop. During this workshop, teacher A and B shared their previous science teaching experiences, learned about the knowledge building principles, and planed for the rough classroom designs for the school year 2013-2014. In the summer of 2014 and spring of 2015, teacher A and B engaged in another one-day workshop organized by our research team to reflect on their teaching experience in the previous school year and plan for the teaching in the school year 2014-2015. The second phase is a two-year design-based implementation research conducted in another two classrooms taught by teacher B in two successive school years (2014-2015 in classroom A and 2015-2016 in classroom B), with knowledge building practices in classroom A as a baseline for comparison and detailed analyses of classroom B for design implementation. Teacher B had 17 years of Grade 5 science teaching experience. For all the four classes involved in these three studies, students investigated the human body systems over the whole school year as the focal theme of their science curriculum.

The human body inquiry was conducted in line with the principles of knowledge building (Scardamalia, 2002). Instead of following teacher's pre-specified knowledge goals and inquiry procedures, students were expected to take on collective responsibility for co-identifying problems of inquiry and conducting spontaneous inquiry activities to address the problems, with support from their teachers. The whole inquiry unfolded as an open and dynamic process based on problems/questions emerged from knowledge building interactions that gave rise to shared areas of inquiry. The knowledge building processes integrated individual and small group reading and notetaking, searching of libraries and internet resources, modeling and demonstrations, student-directed presentations, small group discussions, and whole class face-to-face conversations. These regular whole class face-to-face conversations are known as "metacognitive meetings" in the classrooms, which are typically carried out with all students sitting in a circle on the carpet of the classroom, sharing their knowledge progress with the whole class. In all science classes, each student was provided with a laptop with Wi-Fi-enabled. Major questions and findings generated through all the classroom activities were contributed to Knowledge Forum for continual knowledge building discourse and idea improvement.

Data collection and analyses

Specifically, rich classroom and online data were collected over the whole school year, including (a) classroom observation notes that recorded major activities, interesting ideas from students, and notable teacher scaffolding in each lesson; (b) video and audio recordings of whole classroom meetings and small-group sessions; (c) photos of classroom artifacts and student notebooks; (d) teacher's reflection journals recorded in Google Drive about major activities and knowledge building progress in each science class; and (e) student online discourse records in Knowledge Forum. According to the purposes of different studies, corresponding analytic approaches were applied to analyze multiple sources of data collected. In all the three studies, we descripted the classroom processes to cogenerate and adapt the collective inquiry structures first. Specifically, we browsed the field notes and teacher's reflection journals to identify major elements of each structure co-generated by different knowledge communities and corresponding classroom moments when the collective inquiry structures were formed and adapted. Then we zoomed into the video records of the classroom moments to understand the specific processes by which the structures were constructed, adapted and used. The classroom videos were transcribed and analyzed using a narrative approach to video analysis (Derry et al., 2010) supported by other related classroom data, including pictures of classroom artifacts and student's notebooks.

To gauge the productivity of students' knowledge building, we analyzed students' collaborative discourse in Knowledge Forum from classroom A and B. First of all, we compared objects of inquiry from the two classrooms based on the evolution of structures objectified as organization of views in Knowledge Forum. In addition, we conducted quantitative analysis with students' contributions in Knowledge Forum over the whole school year. Quantitative measures focused on the words students wrote and the notes students contributed online. Focusing on the growth of the community's knowledge, we then dug deeper into the notes in the shared areas of inquiry using content analysis (Chi, 1997). We coded students' contributions with a five-category coding scheme which captures productive discourse patterns (1=*questioning*, 2=t*heorizing*, 3=*evidence*, 4=*referring resources*, and 5=*connecting and integrating*) (Hmelo-Silver, 2003; Author et al., 2011). Two raters independently code 20% of the notes to assess interrater reliability, which was 89.24% (Cronbach's Alpha =.93). For those notes which were coded as "*theorizing*", a further content analysis was conducted to assess scientific sophistication of “theories/explanations” developed by students based on a 4-point scale (1=*pre-scientific*, 2=*hybrid*, 3=*basically scientific*, and 4=*scientific*), which was verified in our previous research (Author et al., 2007, 2009). Two raters independently coded 20% of the notes labeled as “theorizing” from class A and B in the shared areas of inquiry, resulting in an inter-rater agreement of 91.43% (Cronbach’s Alpha =.92).

Results

How did the community work together to construct and adapt the shared structures to frame what they should investigate?

The analysis of classroom videos, classroom observation notes as well as photos of classroom artifacts and student notebooks identified the reflective processes by which students and teacher A co-generated the shared inquiry structures in the form of “big questions” to frame what they should investigate. These processes are elaborated below.

(a) *Co-generating initial “big questions” of inquiry based on students’ individual research questions.* The inquiry about the human body systems began with a kick-off activity in late September. Students watched a short movie about the human body systems, which triggered deep interests in the amazing functions of the human body. Following the kick-off activity, teacher A organized a whole class reflection for students to share what they’d learned from the movie as well as what they were curious about human body. Teacher A collected all the questions from students and read them one by one in the classroom. Students realized that some of those questions were posing the same or similar issues. Therefore, teacher A suggested his students to work in groups to formulate a high level question that could integrate those related individual questions. Teacher A used the metaphor of a tree trunk and branches to illuminate the relationship between the human body theme and the “big questions” of inquiry cogenerated. Four big groups were formed. Group members worked together to generate a branch question for each small group and shared them with peers. By the end of September, they came up with an initial list of four questions, as the community’s shared goals of inquiry: “Why do we have bones?” “How does our brain function?” “How does the human body develop?” “How does immune system work?” Four corresponding views (workspaces) were set up in Knowledge Forum to support their online knowledge building discourse.

(b) *Conducting inquiry while further expanding and adapting existing “big questions” to include new areas of inquiry.* Guided by the initial four “big questions”, students worked with peers to carry out research using books, websites, and models. Important facts and ideas obtained from individual and small group inquiry were shared online in Knowledge Forum. In their science class, members interested in each “big question” found a spot in the classroom to meet. With their notebooks open, they shared new advances including new facts, theories, questions, as well as possible strategies to do deeper work or share their recent findings. As the inquiry proceeded, students generated more specific questions. In early October, the whole class had a face to face meeting to share and reflect on collective knowledge progress. Teacher A projected the Knowledge Forum notes on a screen in the classroom and read them to the students. Some students noticed that some of the notes “didn’t fit existing ‘big questions’”. They suggested that they might need new “big questions”. Based on some new notes about food and water in Knowledge Forum, they worked together to frame the fifth “big question”— “Why do we have a digestion system?” The sixth “big question” was added in the same way based on some new notes about heart and blood:
“Why does blood circulate through the human body?” To highlight these “big questions” to the whole class as a guide, teacher A them on a large chart paper, which was hung on a wall in the classroom. Once the new emergent “big questions” was officially announced, some students decided to leave their previous group and move to the new questions which they thought they were more interested in. Teacher A found it’s the right time to “relocate” the students. Each student then chose one big question as his/her focal area

and added her/his name on a sticker note next to the question, leading to the formation of six temporary research groups (see Figure 1).

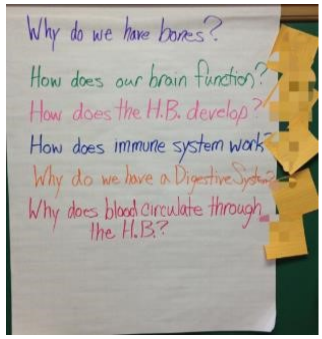
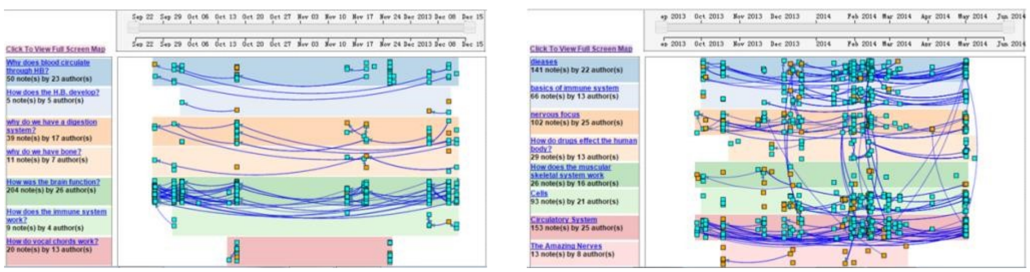


Figure 1. A List of Six "Big Questions" Co-generated by the Community.

The community was open to generate new questions emerged from inquiry. Teacher A kept encouraging students to add more "branches" onto the question list if none of the questions reflected their focal interest. In early October, a girl (student A) read a book named Kids InfoBits. She was really interested in the part about vocal cords and took some notes in her notebook. Even though she had signed up for the immune system group, she talked to teacher A about her new interest and findings about how vocal cords work. Meanwhile, another student (student B) who was still hesitant about which group he should join in, read the magazine Science Spin (Primary). He took some notes about how sound is produced through air vibration. Since he was not sure about the big questions he should focus on, the teacher suggested that he started with what he was working on. The third student (student C), who had signed up for the immune system group, sitting next to student B, indicated the same interest in vocal cords. Student C had already taken some notes about pitches of vocal cords after watching some movies on the BrainPop site. Then teacher A approved of these three students' proposal to start research on vocal cords. Student D, who had not decided a focus area, also showed interest in this new question. In the end, these four students formed into a temporary group to study vocal cords. The seventh question, "how do vocal cords work", was added to the collective "big question" list in middle October. Later, through a whole class reflection on knowledge advancement, students identified new "big questions" through expanding existing "big questions" of inquiry. In middle December, two new questions were identified: "Why do we have respiratory system?" "How do human body cells work?" In early January, a student proposed a question about muscles as a new big question. He thought there was no questions about muscles so far. His peers who investigated bones suggested that the question about muscles could be integrated in the existing question about bones as the two were so closely related. Therefore, the first big question was renamed as "why do we have muscular and skeleton system?" Altogether nine "big questions", representing the shared goals of inquiry, were progressively formulated and continually investigated in the rest of the school year.

(c) *Collective reflection aided by ITM monitor knowledge progress in each "big question" and plan for further inquiry in new (weak) areas*. As new questions of inquiry emerged from ongoing knowledge building activities, more and more students switched to new areas. In early January, the whole class decided to review where they were in their online discourse and where to go next for further inquiry. Teacher A introduced ITM as a tool to help students organize and review the contributions the whole community made around each "big question" in Knowledge Forum. Teacher A modeled the use of ITM by constructing one idea thread as an example. Then he invited students to construct idea threads for the "big questions" they had worked on. Based on the first seven "big questions" identified before December, seven temporary small-groups were formed. For those who had moved onto new questions of inquiry, they returned to their previous group and reviewed the knowledge progress their community had made. To ease the process of ITM use, students were first provided with several pages of printouts of the notes posted in Knowledge Forum. Students reviewed the notes and highlighted the ones that addressed their focal questions. Teacher A and I helped to import the notes identified by each small group in Knowledge Forum to ITM. ITM displayed the notes highlighted by students on a timeline as one idea thread and retrieved authors involved in each line of work, with options to show build-on connections over time. Follow this process, seven idea threads were constructed and mapped out on the same timeline (see Figure 2a): 1) why do we have bone? 2) how does the brain function? 3) how does the human body develop? 4) how does the immune system work? 5) why do we have a digestion system? 6) why does the blood circulate? 7) how do vocal cords work?

In late May, students had another reflection with ITM to review the knowledge progress in active areas of inquiry after the first reflection in January. When working on the keywords to search notes on KF, students focusing on the nervous system and immune system found they had rich contents addressed, so they decided to break down into several sub-groups focusing on more specific issues. Eventually, eight idea threads were created (see Figure 2b): 1) how does the muscular and skeletal system work; 2) nervous focus (basics of nervous system); 3) the amazing nerves (the functions of nerves in messaging); 4) basics of immune system; 5) diseases; 6) how do drugs affect the human body; 7) circulatory system; and 8) cells. Comparing the intensity of notes created in each thread in the two ITM-aided reflection sessions, it is obvious that more new contributions were made after the first reflection from early February to March. With reflective monitoring of progress in each collective goal through idea thread, students made purposeful contributions and collaboration in subsequent work.



(a) (b)

Figure 2. Idea Threads Created Corresponding to Each "Big Question" in Early January and Late May.

How did students and teacher A co-construct and adapt the "research cycle" model to guide their inquiry process?

The analysis of the observation notes and classroom videos identified the reflective processes by which the community generated and adapted the "research cycle" model to inform and guide members' inquiry actions. These processes were elaborated below.

(a) *Reflecting on individual intuitive inquiry experiences to develop a shared sense of the research journey.* Students began their inquiry about the human body in mid-September. Without specified inquiry procedures provided by teacher A, students worked on the focal questions based on prior science learning experience to collect information and answer their questions. Notably, students applied various reading strategies (e.g. note taking) acquired in their previous learning to their research involving books and other materials. Teacher A observed students' research activities in the classroom and occasionally asked questions to help students articulate their thoughts and actions, such as: "*What led you to that question?*" "*So you found facts, and then you said, organize them…why would you do that?*" "*What would you do after that?*"

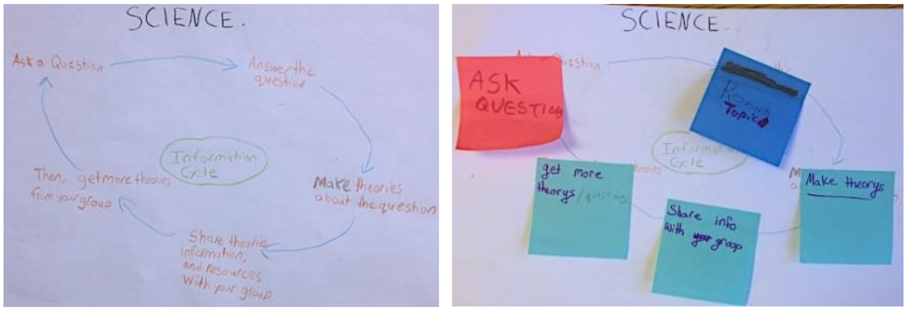
In a whole class discussion about brain damages around mid-October, students engaged in active responses to one another's ideas to offer deeper information, build connection, and raise deeper questions. Teacher A seized this opportunity to facilitate a whole class reflection on how to conduct inquiry. He shared his observation of how student ideas had grown in this discussion and used a metaphor that research was like a journey. Teacher A asked students to reflect on their own journey in terms of where they were now and where to go next in the next phase. He framed two questions to guide students' reflection about their research journey. Students shared their personal answers in small groups and, then, as a whole class. The major points were recorded by teacher A on two pieces of chart paper (see Table 1 for a summary). Students' reflections showed a shared sense of the inquiry process as a continual journey: Once you have learned a lot in an area of inquiry, you can create new theories, ask further questions, and find out even more complex information.

(b) *Co-generating a more systematic group representation of the research cycle through small-group reflection.* With a shared sense of inquiry as a deepening journey, students continued to carry out research and discourse in their focal inquiry areas. With richer experience accumulated in the inquiry processes, teacher A thought it's the time to develop a more systematic representation of the research journey. He suggested that each group reflect on their research journey and create a research cycle to help guide their daily research actions.

Table 1: A synthesis of where individual students was and where to go next.

Teacher's guiding questions	Collective summary based on individual reflection
(Q1) Once you have learned a lot of fascinating information, what has begun to happen?	● Finding more complex information; ● Organizing information to answer questions; ● Making theories and hypotheses from resources; ● Helping others to answer their questions;
(Q2) What are the next steps in a research journey?	● Making new questions out of facts collected; ● Taking theories to make new questions and then make new theories; ● Sharing or demonstrating learning in different ways; ● Answering questions, asking questions…

In total, four small groups generated four different research cycle models, with the following shared components: *asking a question, collecting facts, answering the question, making theories, sharing information and resources, generating more theories, building onto theories, and finding new questions*. Teacher A reminded students that the actions in their cycles were not linear or fixed. Student could change or update the research cycles whenever needed. Each small group referred to their own model of research cycle to plan for the knowledge building work and co-determined what they needed to do for deeper inquiry. It was also used by teacher A to understand where each individual or small group was in their inquiry process and to provide corresponding support for their inquiry. Around mid-December, students worked as groups to re-visit their initial research cycles and refined the components and/or sequence of their inquiry actions based on their accumulated experience and updated understanding of science inquiry. For instance, one of the small groups revisited their initial cycle created in November, in which they had five components: *Ask a question; Answer the question; Make theories about the question; Share theories, information and resources with your group; Then get more theories from your group* (and start over) (see Figure 3a). Then in December, this small group generated an updated cycle (see Figure 3-b) with the following components: *Ask questions; Research topic; Make theories; Share info with group; Get more theories/questions (and start over)*. The updated cycle highlighted the importance of collecting information through research and finding deeper research questions as students developed theories.



(a) (b)

Figure 3. The Initial and Refined Research Cycle from One Small Group.

(c) *Creating a collective research cycle model based on refined research cycles from small groups.* In January, with progress made in the focal areas of inquiry, students shared their knowledge through whole class meetings and writing advanced notes in Knowledge Forum. Students started to work on related new topics of research, with the original groups disbanded or reformed. Teacher A suggested the need for the whole class to synthesize the research cycles created/refined by different groups into a collective model that everyone could use to support her/his research. In a whole class discussion, students reviewed all the four small groups' models, identified common components, and suggested additional components, leading to the creation of a collective research cycle (Figure 3b). The collective research cycle included seven components: *Asking question; Initial research; Post KF/MM* (collective meetings to share knowledge progress); *Theorize; Deeper research; Revise your theory; and Share with class* (then start over). In this whole class discussion, teacher A challenged students to rethink about their inquiry actions and rephrase their actions using more scientific terminology, such as asking, "*harder, you mean more difficult to understand or complex like that*?" "*Take my theories and make a…Can I say 'a new question*?'" Teacher A wrote down the components of the collective research cycle and hung it on the wall in the classroom as a guiding tool for students to plan and conduct specialized inquiry from February to June.

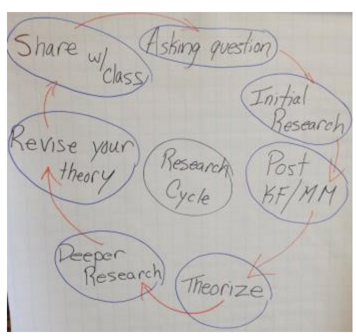


Figure 4. The collective research cycle model co-generated by the community.

(d) *Ongoing adaptive use of the inquiry structures by students*. The structures generated through the aforementioned reflective processes, including the initial framing of the research journey, small group research cycles, and the collective research cycle, assisted students as they planned for their research and reflected on the knowledge progress as a small group and collectively. Teacher A modeled the reflective monitoring of inquiry practices using the co-generated research cycles and purposefully identified examples of strong practices. For example, teacher A noticed that a student was taking research notes in her notebook to summarize new information and generate new questions and theories (see Figure 5). He advertised this practice to her peers, by saying:

> I saw Lily's (pseudonym) notebook. I want to show how she organized (notebook page) …very much like …*a fifth grader scientist's notebook*…And I see here she's got a few

> different questions that she asked. But at the bottom she has theories, right? So.. the questions/theory she got was “how does the neurons work?” …Awesome question! This word right here in fact shows me that she’s made great progress…What I really loved is how it was organized: questions, theories, those things are right there.

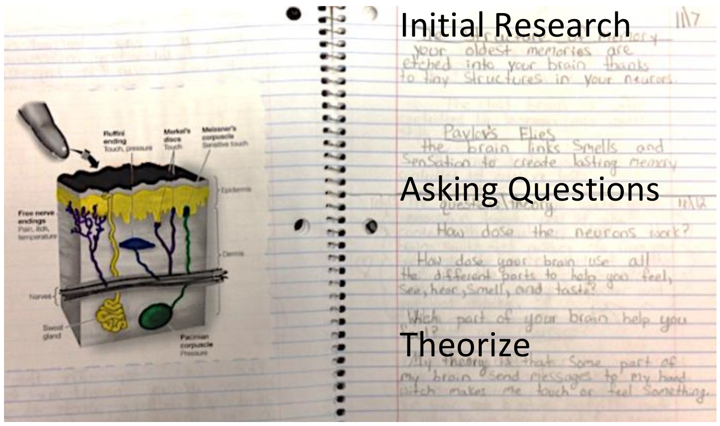


Figure 5. Lily’s Note-taking Aligned with the Actions in the Research Cycle.

In this example, the teacher pointed out specific features in Lily’s notebook to show case key actions of inquiry: layers of questions (how to make a question), theories (initial understanding), and organized facts and information.

How did students and teacher B implement reflective structuration in year 2 to guide knowledge building practices over time?

Qualitative analysis of rich data identified the reflective processes the community worked together to co-generate shared epistemic objects (see Figure 6). Details of the reflective processes are described below.

(a) *Co-formulating collective wonderings based on students’ individual questions.* Prior to the beginning of the school year, the teacher identified the human body systems as the focal topic of the school based on their school district’s curriculum. The inquiry began with ten out-door games designed by the teacher and another Grade 5 science teacher, aiming to engage students in various activities related to different human body systems. These activities triggered students’ initial interests. When they returned to the classroom, the teacher organized a whole class conversation to share their experiences. After that, each student wrote down the question they were most interested in on a sticky note. They also decided together to “*think about their questions and find books that related to their questions to read*”. When they met again to share the progress, each student brought one book about their question. The teacher suggested each student to prepare a post-it sticker and write down the following information on it: “Name”, “My question”, and “Body parts (I’m working on)”. Then students pasted the sticky note on the book they chose, searched for the students who were working on related questions about the same body parts. In this way, students were automatically “grouped” into six small groups. These small groups then worked together to co-frame a bigger question to include each member’s question. In late September, the initial six big questions were identified and hanging on the classroom wall. Corresponding separate spaces were set up in KF, too.

(b) *Re-framing, adapting and updating existing big wonderings to include new objects of inquiry.* Students continued their inquiry from October to December. The teacher, with support from our research team, designed various reflection templates for individuals and small groups to reflect on where they were in their inquiry, new knowledge gained, and where they should go next. When small groups felt they were done with their research about one topic, they asked their teacher for a time slot to hold a whole class meeting to share their knowledge progress and emergent questions of inquiry with peers. New epistemic objects of inquiry were generated based on new questions from ongoing inquiry. During these three months, initial small groups finished the work on their original focal objects disbanded, and re-formed to work on new unfolding big questions (See Figure 6b). New emergent groups formed accordingly to continue their research. Corresponding new spaces were set up in KF for their online knowledge building discourse, too. In late January, all students moved onto new objects of inquiry.

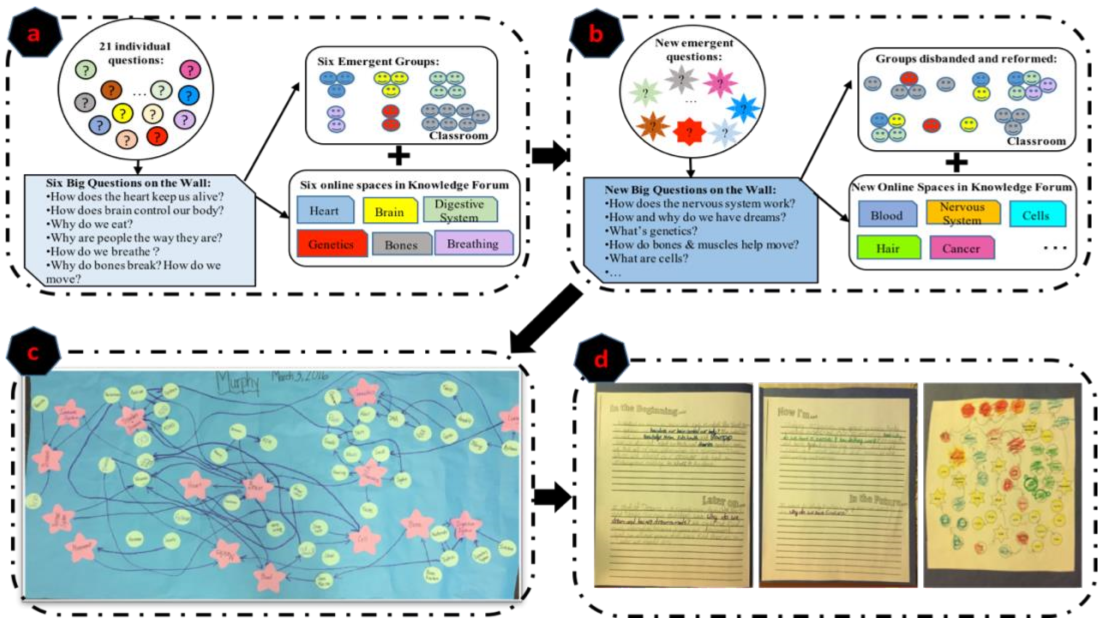


Figure 6. The Reflective Structuration Processes that the Community Co-frame Shared Directions of Inquiry.

(c) *Deep search, framing, and collective mapping of interrelated epistemic objects*. In February, small groups reflected on knowledge progress in new inquiry areas. As more and more new questions were proposed, the community decided to reflect on all the objects they'd investigated so far. Supported by an incomplete list of epistemic objects identified by the teacher, each student started a review of individual inquiry. Based on this individual reflection, the whole class conducted two collective conversations to identify collective epistemic objects and the connections among them. Meanwhile, emergent objects that were missing in the initial prepared list and new objects that no one in the community had worked on before were identified (see Figure 6c). The teacher hung the collective objects map on the classroom wall for students to refer to for further inquiry.

(d) *Individual and small-group reflection and planning for specialized inquiry aided by the collective objects map*. After the co-generation of the collective objects map, students continued their work to prepare for a science symposium as a way to share all their knowledge gain with their peers, parents, and students from other grade 5 classrooms. As a product for the symposium, each kid wrote an individual journey of thinking about all the objects they investigated and the objects they plan to research soon (see Figure 6d). Finally, their collective reflection on where to go next led collective inquiry to more specialized objects. Some kids began to work on the objects that were missing on the collective map, like "*kidney*". Some other kids moved onto other objects that was researched by their peer but they had not investigated yet because they wanted to know more about the human body.

While using the collective map of the inquiry objects to guide knowledge building, the community remained open and reflective about new possible directions and connections. A whole classroom conversation was held to review how the various lines of inquiry were connected. Before the collective reflection, the teacher worked with our research team to identify an incomplete list of objects investigated by all students based on their face-to-face and online knowledge building discourse. One student noticed that almost every object of inquiry connected to brain. That led to the whole class discussion with the brain as an object in the center. Other objects were added one by one based on the connections among them proposed by students. During this process, three new major objects (see the pink stars in Figure 6c) were added/adapted (*genetics, immune systems, and 5 senses was promoted*); seven new small objects (see green circles in Figure 6c) were identified (*O.C.D., A.D.D., red blood cells, white blood cells, pain, nails, and virus*); 25 new connections were made; as well as one "not-yet" object (*kidney*) was recognized.

Did the reflective structuration approach leverage sustained and productive knowledge building practices? To what extent, and in what ways?

(a) The number of objects and number of contributions in each object from classroom A and B.

As elaborated in the classroom implementation section, each epistemic object of inquiry emerged from reflective interactions across different social levels and further functioned as shared focus of knowledge building work in the classroom and Knowledge Forum. In classroom A, with the facilitation from the teacher, students co-identified five objects of inquiry as a list of overarching goals to guide intentional knowledge building in relevant areas (see Figure 7). In classroom B, students co-framed similar overarching goals like classroom A in the beginning. However, through continual reflection on what they were investigating and what the deeper questions were, students in classroom B kept searching for progressive and connected objects of inquiry to adapt existing structure of inquiry (see Figure 7).

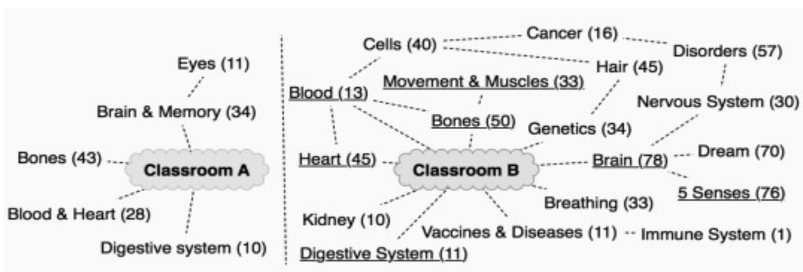


Figure 7. Objects of Inquiry and Number of Contributions in Each Object from Classroom A and B

(b) Content analyses of student contributions in investigating shared objects of inquiry in Knowledge Forum We compared student contribution in Knowledge Forum in terms of the number of notes contributed by each student. Compared with students from classroom A who wrote 24 notes on average, each student in classroom B wrote 36 notes. To see how different designs affected students' knowledge building actions and contributions as reflected in their online discourse in the shared objects of inquiry from classroom A and B, we traced the contributions they made in Knowledge Forum. As Figure 8 shows, compared with classroom A, when investigating the five shared objects, classroom B made more purposeful contributions by asking more relevant questions, developing even more explanations to answer their questions. While students from classroom A used both intuitive experience, examples from daily life, and resources from webpages and books to support their explanations, students from classroom B were more inclined to refer to online resources and books to improve their ideas and ask deeper questions. And finally, students from classroom B were able to develop more high level understandings by synthesizing different ideas and theories to answer their focal questions.

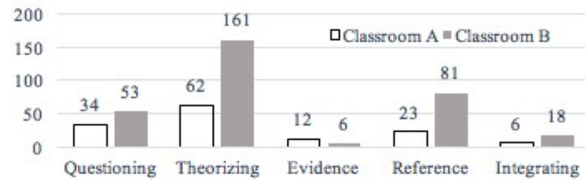


Figure 8. Contribution to Shared Objects of Inquiry from Classroom A and B

The understandings related to each object of inquiry were further coded based on scientific sophistication to examine the extent to which students' explanations align with a scientific framework of human body systems (see Table 2). Through sustained and purposeful knowledge building work supported by collective structures, students in class B (M=3.41, SD=0.17) were able to develop a higher level of scientific sophistication of ideas in all objects of inquiry than class A (M=2.70; SD=0.37); $t(8)$=3.91, p=0.01. Specifically, the average scientific rating of students' ideas in all five shared objects from class B was between "*3 – basically scientific*" and "*4 - scientific*", compared with in class A between "*2 - hybrid*" and "*3 – basically scientific*".

Table 2: Scientific quality of explanations about shared objects of inquiry (Means and Standard Deviations).

Classroom	Scientific sophistication of ideas				
	Bones	Blood & Heart	Digestive System	Brain & Memory	Eyes (5 Senses)
A	2.46 (0.84)	3.2 (1.03)	3 (0.82)	2.46 (0.88)	2.4 (0.55)
B	3.42 (0.61)	3.31 (0.83)	3.5 (0.53)	3.2 (0.73)	3.63 (0.49)

Discussion

The first two case studies provide a detailed account of how two Grade 5 science communities co-constructed and adapted shared structures represented as a list of evolving "big questions" and a "research cycle" model. The emergence of the "big questions" and collective research cycles underwent several similar iterative cycles of reflective talks: : Students reflected on wonders about human body (research journey during the first phase of inquiry) to make the individual questions they were interested in (prior intuitive actions of inquiry visible); Small group members worked together to co-frame a big question (build a local small group research cycle) that helped to guide the inquiry of group members. These big questions (research cycles) from the small groups were shared and discussed in a whole class discussion and used by the small groups to guide their inquiry actions for a period of time. With accumulated experience from ongoing inquiry, students added new question to expand existing big questions list (refined the research cycle). As the inquiry proceeded, students then reconvened as a whole community to review existing big question and include more big questions (generate a collective model of research cycles), which was presented on a large poster, as a structure-bearing artifact.

This design-based study investigated the generation/adaption, and use of collective epistemic objects to sustain knowledge building practices in Grade 5 science classrooms. First, qualitative analyses traced the evolution of the structuration process guided by the shared structure of epistemic objects, which helped the community to frame and reframe its collective focus of inquiry related to human body systems in classroom B. The collective focus was coconstructed as an evolving list of collective wondering areas, each of which had its focal object(s) of inquiry and overarching question(s), with students generating more specific research questions to guide their contributions. The collective objects of inquiry were co-constructed and continually adapted by the community through metacognitive conversations in reflection of members' diverse input and ongoing progress. These collective goals were represented and highlighted using classroom artifacts (e.g. collective question list, and a collective map of all objects of inquiry) to guide student attention and participation. The analyses of online discourse from both classrooms illustrated to what extent and in what ways the reflective structuration design impacted students' knowledge building engagement in Knowledge Forum. Both classrooms used the initial wondering lists to organize their continual knowledge building online. As Figure 7 shows, through continual reflection on what they were investigating and what the deeper questions were, students in classroom B kept searching for progressive and connected objects of inquiry to adapt existing structure of epistemic objects, which made the inquiry more productive (Figure 7). With purposeful contributions in each areas, they asked more questions and developed more explanations (see Figure 8). By continual improving their eixisting theories, classroom B were able to develop a higher level of scientific sophistication of ideas in all shared objects of inquiry than classroom A (see Table 2).

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