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Forming shared inquiry structures to support knowledge building in a grade 5 community

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Abstract
This study explores the reflective processes by which a grade 5 science community co-constructed shared inquiry structures to focus and guide its inquiry about human body systems over a school year supported by a collaborative online environment. The co-constructed structures included a list of collective wondering areas as the shared focus of inquiry and models of the inquiry process in the form of "research cycle." Qualitative analyses of field notes, classroom videos, student notebooks and interviews elaborate the evolution of the inquiry areas and the "research cycle" model as well as students' adaptive use of the structures to guide deeper inquiry. Content analyses of students' individual research questions and collaborative online discourse indicate that students used the structures to develop more advanced inquiry and make productive contributions. The results contribute to elaborating a reflective structuration approach to co-organizing and sustaining long-term, open-ended inquiry in knowledge building communities.

Keywords Learning community · Knowledge building · Reflective structuration · Inquiry structures

Introduction

Research on learning communities suggests a model of education that engages students in collaborative, inquiry-based practices to develop deep understanding (Bielaczyc and Collins 1999). Beyond implementing collaborative, inquiry-based tasks, efforts to create learning communities need to enable substantive classroom changes in line with how knowledge is processed in real-world knowledge communities (Bielaczyc 2006; Bielaczyc and Collins 2006; Scardamalia and Bereiter 2006). In authentic knowledge communities, members advance collective knowledge through sustained, discursive, and inquiry-based practices. They produce tentative theories and engage in idea-centered dialogues involving multiple perspectives, constructive criticism, and distributed expertise. They also take on

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high-level agency and collective responsibility for coordinating joint actions, monitoring their knowledge progress, and planning for sustained inquiry (Scardamalia 2002). Deeper challenges and goals emerge as new solutions and ideas are developed, driving sustained idea advancement (Zhang et al. 2011; Zhang et al. 2009). However, implementing sustained inquiry in classrooms in which students take on high-level collective responsibility is challenging. Underlying this challenge is a knowledge gap regarding how student-driven inquiry and collaboration may be socially organized and pedagogically supported in the classroom to address educational goals and contextual constraints. Our recent research reveals a socio-epistemic mechanism, which we term "reflective structuration," through which classroom communities enact collective responsibility by constructing shared inquiry structures to guide and support their knowledge building practices (Zhang et al. 2018). The current study investigates the processes by which a grade 5 science community co-constructed and adapted collective structures of inquiry to guide and support its inquiry over a whole school year.

Supporting authentic and sustained inquiry practices in learning communities

Recent reforms in science education call for efforts to engage students in authentic and sustained scientific practices in line with how scientific knowledge is constructed and practiced in the real world (e.g. National Research Council 2012; NGSS Lead States 2013). These include asking questions and defining problems, making observations, designing experiments, refining scientific explanations through collaborative discourse, planning and monitoring inquiry processes, and so forth. To make the inquiry-based processes authentic, educators need to help students to take on high-level responsibility over each of these components of inquiry (Chinn and Malhotra 2002). Students identify their driving needs of inquiry (Duggan and Gott 2002; Flum and Kaplan 2006; Kuhn 2007), position and monitor their inquiry actions, and pursue emergent goals as part of a long-term, purposeful inquiry trajectory (Scardamalia 2002). Through such efforts, students come to make sense of the world around them and understand the epistemic nature of inquiry (Barzilai and Chinn 2018; Littleton and Kerawalla 2012).

Despite the call for authentic and sustained inquiry, current inquiry-based learning practices are often short and oversimplified, requiring students to finish given hands-on tasks within a few lesson hours. Such practices may only result in a fragmented and disjointed picture of science practices (Crawford 2000; Osborne and Collins 2001). Students miss the opportunity to engage in high-level epistemic decision-making about what the inquiry should focus on, how to pursue their inquiry and discourse, and who should play what types of roles (Zhang et al. 2018; see also, Blanchard et al. 2010; Chinn and Malhotra 2002).

Aligned with the need of authentic scientific practices, research on learning communities has led to various research-based collaborative inquiry programs (e.g., Bielaczyc and Collins 1999; Brown and Campione 1996; Engle and Conant 2002; Fong and Slotta this issue; Scardamalia and Bereiter 2006; Slotta et al. 2014). Working as a community, students engage in collaborative discourse and joint practices to advance collective understandings, leveraging students' personal growth and learning. Their collaborative discourse and inquiry integrates specific socio-cognitive moves such as generating progressive questions, theorizing and explaining, examining evidence, building on peers' ideas, and reflecting on progress (Damşa 2014; Hakkarainen 2003; Hmelo-Silver 2003; Mercer and Littleton 2007; van Aalst 2009; Zhang et al. 2007).

To enable deep classroom transformation in line with the principles of learning communities, new designs are needed to support students' engagement in sustained collaborative inquiry over weeks or months; and, at the same time, to foster students' high-level agency and collective responsibility for dynamic idea advancement (Bielaczyc and Ow 2014; Scardamalia 2002). Research on learning communities underscores students' responsibility and agency in collaborative, inquiry-based practices (Bielaczyc and Collins 1999; Engle and Conant 2002; Scardamalia and Bereiter 2006). To implement collaborative inquiry under ordinary classroom conditions and deal with students' gaps in inquiry skills, current dominant designs of collaborative inquiry tend to scaffold learners using carefully designed structures and scripts, which specify, sequence, and distribute various task operations among learners in order to guide effective interactions (Fischer et al. 2013; Kirschner and Erkens 2013; Krajcik and Shin 2014). While such carefully designed structures and scripts have important pedagogical value, researchers need to deal with the tension between the need to provide guidance structures and that to foster student agency for charting and deepening the course of their inquiry. The structure-agency tension has become a core issue in the ongoing debate about how to support students' collaborative learning and knowledge building (Bereiter et al. 2017; Dillenbourg 2002; Hod et al. 2018). Addressing this tension is essential to enabling productive inquiry with pedagogical effectiveness while avoiding oversimplified inquiry and collaboration.

This research explores new mechanisms and designs to support students' long-term collaborative inquiry in a way that engages their high-level agency. We conducted this research in the context of knowledge building communities, a model of learning communities aimed to engage students in authentic knowledge-creating processes to advance ideas of value to their community (Scardamalia and Bereiter 2006). In the larger family of inquiry-based programs, Knowledge Building pedagogy is unique in adopting a principle-based, open inquiry model for sustained idea improvement (Scardamalia and Bereiter 2007). Students are expected to take over responsibility typically assumed by the teacher, such as defining problems, planning and monitoring inquiry progress, generating and assessing theories and explanations, and continually identifying deepening questions that drive long-term inquiry (Scardamalia 2002). Instead of following predefined project activities and procedures, the teacher and students co-construct and reconstruct the flow of inquiry processes as their work proceeds, guided by a set of knowledge building principles. The principles include *authentic problems and real ideas, knowledge building discourse, collective responsibility for the community's knowledge, epistemic agency*, and so forth (Scardamalia 2002). Research shows that productive knowledge building communities are able to work with the flexible, principle-based approach to classroom processes to achieve productive outcomes (Chen and Hong 2016; Zhang et al. 2011). A challenge for researchers is to demystify how the student-driven, open-ended, and dynamic process of inquiry becomes sufficiently organized and supported without extensive teacher prescripting and step-by-step guidance.

Forming shared inquiry structures to support knowledge building: a reflective structuration approach

To address the above-identified challenge, we developed a reflective structuration perspective to explain how student-driven, dynamic knowledge practices become socially organized and supported in a community (Zhang 2013; Zhang et al. 2018). The notion has grown out of our previous studies of knowledge building practices in primary school classrooms (Tao et al. 2015; Zhang et al. 2009; Zhang and Messina 2010). The analyses revealed rich support structures used by the communities to guide student participation and interactions. While some of the structures were primarily introduced by the teacher, a substantial set of structures was co-constructed by students with their teacher's input. For example, in a Grade 5 inquiry about human body systems, students shared individual, interest-driven questions and co-reviewed their questions to generate shared areas of inquiry. The list of inquiry areas was recorded on a piece of chart paper, which was hung on the classroom wall to highlight the scope and directions of collective inquiry. The inquiry areas were used as a referential structure to form flexible groups, guide deepening research efforts, and support reflection on knowledge progress in the unfolding lines of inquiry (Tao et al. 2015). Guided by the co-constructed structures, students did not solely rely on their teacher to tell them what to do and guide them through the inquiry process.

Drawing upon these analyses, we identified reflective structuration as a socio-epistemic mechanism by which inquiry-based knowledge practices become organized and supported over time (Zhang et al. 2018). *Reflective structuration* refers to the reflective processes by which members of a community co-construct shared inquiry structures over time to channel their personal 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). The co-constructed inquiry structures 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 the inquiry structures.

Our recent research elaborates three key points of reflective structuration (Zhang et al. 2018). First, members in a community can co-construct inquiry structures as they build domain knowledge. The inquiry structures provide shared interpretative frames of the unfolding inquiry practices, including (a) shared frames about *what* the community needs to investigate and pursue in a knowledge building initiative, such as the overarching focus and unfolding directions/strands of inquiry; (b) social configurations about *who* work on what in connection with whom; (c) process structure about *how* the community should conduct research and collaborate to advance collective knowledge; and (d) principled values and beliefs used to justify *why* the community should operate in certain ways. The structures are reified and represented using various structure-bearing artifacts and resources, such as using a chart of high-potential problems, which were called "juicy questions" by teachers and students, to highlight the inquiry foci and directions (Tao et al. 2015; Zhang et al. 2018).

Second, there is a dynamic temporal interplay between the two layers of construction to build collective inquiry structures while building and advancing domain knowledge. A classroom community appropriates and builds on existing structures (e.g. a curriculum area) to formulate *initial inquiry structures*. The initial structures serve to set up a largely open stage for students to carry out exploratory inquiry and discourse. The structures mediate students' *actions and interactions* through their reflective use of the structure to plan and monitor their work. The ongoing interactions driven by students' diverse ideas give rise to new inquiry directions and processes. Such changes in turn lead to further *structural elaboration and modification* as intended or unintended consequences. New structures are progressively constructed and adapted to address the emergent needs and opportunities.

Third, co-constructing shared inquiry structures provides a means to progressively engage students' agency and collective responsibility. In an inquiry initiative that may last over several weeks or months, students may start their work with initial structures incorporated by their teacher. As their work proceeds, they can review emergent changes in their community and form new and more elaborated structures to organize their collaborative inquiry. Supported by the structures, students can direct their ongoing inquiry efforts in concert with the evolving agenda of their community to make intentional contributions, monitor progress, and reshape the inquiry structures over time together with their teacher.

Thus, reflective structuration renders new classroom dynamics essential to sustaining creative inquiry practices. Different from pre-scripted inquiry structures, which are analogous to designed paths in a public space to direct people's actions, co-constructed structures are similar to emergent desire lines (or social trails) formed naturally by pedestrians as they take the best paths to get to their points of interest (cf. Sawyer 2005). The reflective structuration approach captures and builds on emergent desire lines—student-generated inquiry interests, directions, and process patterns—in the shared knowledge space to organize and reorganize the inquiry practices of a community.

To examine the process and impact of reflective structuration, we recently conducted a study in two upper primary school classrooms that investigated electricity. One classroom implemented systematic processes of reflective structuration. Members began their inquiry with a general overarching area of inquiry—electricity—appropriated from the school's curriculum. Drawing upon students' initial questions and interests, they co-formulated a network of core "juicy" topics of inquiry, each of which became the focus of an unfolding strand of inquiry involving a cluster of contributing members. Students further documented their idea progress and problems in each line of inquiry, planned for deeper actions over time, and highlighted cross-topic connections to inform collaboration. With reflective structuration, students made more active and connected contributions, leading to deeper and more coherent understandings of a broader set of inquiry topics (Zhang et al. 2018). The teacher played important roles in co-constructing the inquiry structures with students, including mediating the appropriation of the overarching inquiry area from the school's curriculum, seeding potential directions of inquiry through selected learning materials and activities, facilitating and modeling reflective conversations, capturing and reifying the structures emerged using online and classroom artifacts, and ongoing referencing of the "juicy" topics in classroom conversations to guide student participation and reflection.

Through the above study as well as other analyses (e.g. Tao et al. 2015; Zhang 2013), we have investigated how students co-construct structures to frame their inquiry focus and areas, focusing on *what* their community needs to investigate. Further research needs to examine the construction of process-oriented structures to frame *how* the inquiry process can be approached and organized to achieve the community's goals. Inquiry-based programs often structure the inquiry process as pre-defined stages and procedural steps to complete the driving tasks. The knowledge building pedagogy approaches student inquiry as an idea-centered, ever-deepening process consistent with knowledge work in scientific research communities or knowledge-creating organizations (Scardamalia and Bereiter 2006). Socializing students into such dynamic and authentic practice is challenging. To scaffold students' inquiry for idea improvement, Bielaczyc and Ow (2014) designed various "think cards" to help explicate the epistemic operations, such as Our Problem, Initial Theories, Investigative Work, Exchange of Ideas, Improved Theories, Pull-Together, and so forth. A meaningful further step is to explore how students, with support from their teacher, may take on the initiative to frame the essential components of the inquiry process for progressive idea improvement.

Research goal and questions

The current study aims to further elaborate classroom processes by which students and their teacher co-construct inquiry structures to support their knowledge building. It is part of a multi-year, design-based research program in a set of Grade 5 classrooms. The aforementioned analysis (Tao et al. 2015) documented the work conducted in the first year of this research, focusing on how a Grade 5 science community co-generated collective inquiry areas and goals to guide its knowledge building about human body systems over a school year. The current study analyzes data collected from the same classroom in the following school year. The same teacher worked with a different cohort of students to investigate human body systems using knowledge building pedagogy and Knowledge Forum (Scardamalia and Bereiter 2006), an online collaborative platform that supports students' knowledge building work and collaborative discourse. The purpose of this study is to provide an elaborated account of how the teacher worked with the students to co-construct inquiry structures concerning what the community should investigate and how the community should conduct its inquiry. The research questions are:

(a) How did the students and their teacher work together to co-construct and adapt inquiry structures to frame what they should research in terms of inquiry areas and big "juicy" questions?
(b) How did they co-construct and adapt inquiry structures about how to do research, represented as a model of "research cycle"?
(c) In what ways did students use the co-constructed "research cycles" to deepen their inquiry and support their participation in knowledge building?

Method

Participants and contexts

This study was conducted in a grade 5 classroom at a public elementary school located in a suburban school district in northeastern U.S. The classroom had 19 students who were 10–11 years old. The students investigated human body systems over a whole school year (2014–2015) as the focus of their science curriculum. There were two science lessons each week. The teacher had 18 years of experience teaching elementary school students and one year of prior experience with knowledge building pedagogy and Knowledge Forum. In the summer of 2014, the teacher participated in a one-day workshop with our research team to understand the knowledge building principles (Scardamalia 2002) and apply them to the design of the human body systems inquiry.

Instead of following teacher's pre-specified inquiry 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 teacher. The whole inquiry unfolded as an open and dynamic process based on the questions that emerged from knowledge building interactions and gave rise to shared directions of inquiry. The knowledge building processes integrated individual and small group readings and note-taking, searching of library and online resources, small group discussions, whole class face-to-face conversations, model-building, and student-directed presentations. Meanwhile, major questions and findings generated through these classroom-based activities were contributed to Knowledge Forum for continual knowledge building discourse and idea improvement. Their online space was organized as different *views* (workspaces) corresponding to their major areas of research (see Fig. 1). Students wrote *notes* to contribute questions, ideas, and information sources, and *built on* one another's notes to engage in interactive discourse, which mirrored and extended students' interactive conversations in the classroom.

In the various inquiry activities, the teacher positioned himself as a facilitator and co-learner. He encouraged students to take on collective responsibility to co-identify research goals, plan for collaborative activities, and reflect on ongoing progress. As a specific strategy to support collective planning and reflection, the teachers facilitated "metacognitive meetings" (MMs for short by students): face-to-face class meetings in which all students discussed what important questions they needed to research, what knowledge progress had been made, and how they should conduct research to address emergent problems. As an important product of the metacognitive meetings, the class generated various artifacts to highlight shared structures of inquiry. These included constructing a list of wondering

Fig. 1 A Knowledge Forum (version 4.8) view about "blood and bone marrow" with two example notes

areas and big "juicy" questions to highlight the collective focus of inquiry and creating a "research cycle" chart to frame the processes of the inquiry. Detailed classroom processes to generate and adapt these structures are elaborated in the results section.

Data collection and analyses

The first author observed every science lesson and collected various forms of data. The data sources included (a) classroom observation notes that recorded major activities, important ideas from students, and notable teacher scaffolding in each lesson; (b) video and audio recordings of whole class meetings and small-group sessions; (c) photos of classroom artifacts and student notebooks; (d) student interviews focusing on how they used the collective structure represented as "research cycle" to guide their inquiry; and (e) online discourse records in Knowledge Forum.

To address the first two research questions about how the community constructed and adapted inquiry structures, we used our classroom observation notes to identify major structure elements generated. To structure what they should investigate, members of the community co-generated and adapted a collective list of inquiry areas and questions. As a structure about how to do research, they co-developed and adapted a "research cycle" model that included important actions of knowledge building. Based on our observation notes, we identified the critical moments when the inquiry areas/questions and "research cycles" were formed, adapted, and shared using the related classroom artifacts. We then selectively zoomed into the video records of the classroom moments to understand the processes by which these 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 students' notebooks and classroom artifacts (e.g. small group research cycles). The construction of the narrative based on the videos and other data focused on capturing the reflective processes enacted by the students and teacher to appropriate, produce, use, and modify various collective structures to frame the focus and processes of inquiry. Specifically, we first browsed the videos and transcriptions to develop an overall sense of the reflective processes, and then identified "digestible" chunks in the videos—major episodes of the reflective conversations in which students negotiated overarching "juicy" questions, generated the "research cycles," and planned for deeper inquiries. These chunks of videos were analyzed to capture who enacted what kinds of reflective processes to develop what sorts of structures and related artifacts or resources. The video episodes were further contextualized through building chronological links among the episodes and with our observation notes to construct a storyline.

To understand how students used the "research cycles" to support and guide their inquiry, we interviewed seven students who agreed to share their comments on their inquiry. The interviews were transcribed and analyzed with open coding (Charmaz 2006) to identify the ways in which students used the structure to support their inquiry. Complementing the analysis of student interviews, we further examined the patterns of inquiry reflected in their notebooks and in the online discourse before and after the formation of the "research cycles." The "research cycles" highlighted the action for students to formulate progressively deeper questions through their inquiry. Therefore, we traced each student's research questions recorded in their notebooks in September and later in May and coded the questions using a "Structure-Behavior-Function" (SBF) framework (Hmelo-Silver and Pfeffer 2004; Hmelo-Silver et al. 2007) (see Table 1). Deeper questions about human body

Table 1 Structure-behavior-function coding of students' inquiry questions

Category	Definition	Example
Structure	Structure refers to the "what" or the elements of a system	What are the different parts of brain?
Behavior	Behaviors refer to the "how", the mechanisms that enable structures to achieve their function and mechanisms of how the structures of a system achieve their outcome or function	How does bone marrow make blood?
Function	Functions focus on the aspects of the system relating to how particular components enable overall system function/role of an element in a system	What causes schizophrenia?

systems need to go beyond factual information about the body parts (body structure) to focus on the processes (system behavior) by which the body parts work together to achieve their functions. Two raters independently coded students' individual research questions, resulting in an inter-rater agreement of 97.1% (Cohen's Kappa = 0.95).

We further analyzed student contributions to their collective discourse in Knowledge Forum as related to the action components highlighted in the "research cycle." Using content analysis (Chi 1997), we coded each Knowledge Forum note ($n = 874$) based on the coding scheme shown in Table 2. In line with the actions in the "research cycle," the level 1 coding categories included questioning, theorizing and explaining, collecting evidence and referencing sources as two primary ways of doing research, and connecting/integrating ideas for knowledge sharing. Under the level 1 categories, a set of codes were included to capture more specific patterns of discourse (Hmelo-Silver 2003; Zhang et al. 2007): factual question versus explanatory question; idea initiating wonderment versus idea deepening question; intuitive explanation, alternative explanation versus refined explanation, and evidence. A second coder coded 20% of the notes to assess inter-rater reliability, with an inter-rater agreement of 94.7% (Cohen's Kappa = 0.94).

Results

We report our analyses to address the three research questions. As noted earlier, the processes to build shared inquiry structures and to use the structures to conduct inquiry are deeply intertwined. Therefore, the analyses of the three questions are interconnected.

How did the students and their teacher co-construct and adapt the inquiry areas and "juicy" questions to focus their knowledge building?

Through the analysis of the classroom videos supported by other data, we identified the following reflective processes by which the community co-generated inquiry structures to frame what they should investigate: (a) co-generating initial inquiry areas based on students' individual research questions; (b) elaborating and expanding the list of inquiry areas based on new emergent questions as the knowledge building work proceeded; and (c) developing specialized research topics to guide and sustain more advanced inquiry. Table 3

Table 2 Coding scheme for students' online knowledge building discourse

Level 1	Level 2	Description	Example
Questioning	Factual question	Questions asking for factual information	What does the word "Immune" mean?
	Explanatory question	Questions in search of explanations	Why do we get migraines?
	Idea-initiating wonderment	Questions that search for general information about a theme-based area	… How do you think allergies work?
	Idea-deepening/elaborating question	Questions that search for deeper and more specific information on the basis of ideas discussed	Nerves might help with sending messages to the brain or receiving messages…But do you have nerves in your brain?
Theorizing/Explaining	Intuitive explanation	An intuitive theory to explain certain phenomenon or issue based on personal experience using informal language	You basically tell the brain what you want it to do and then your body will do it. I'm not a hundred percent sure how the brain sends messages to the body but this was just my theory
	Alternative explanation	A statement that suggests a possible different explanation in disagreement or conflict with existing explanation(s)	We disagree because bacteria are not allergies. It's something that is totally different. And there are also different ways to release bacteria. On the note of allergies, the Epi-pen releases a medication a little like Benadryl, except way more powerful that helps open up your airway
	Refined explanation	An elaborated account of the specific processes and mechanisms using disciplinary concepts/terms	I think that your brain sends messages through the nerves. The nerves notice something in need of a message, they send it through the nerves in the spine and into the brain. The brain finds a solution, and sends the answer back through the nerves. Like if the surface under your hand gets hot…
Collecting Evidence		A posting that describes experiments, and observations to either support or challenge an explanation	The evidence shows that shorter words and words that are somewhat about the same thing are much easier to understand than longer words or completely random words

Table 2 (continued)

Level 1	Level 2	Description	Example
Referencing sources		A posting that introduces information from readings or websites and uses the information to deepen ideas and generate questions	The brain is divided into three main sections: the forebrain, cerebellum and the brain stem. The main part of the forebrain is the cerebrum which makes up about 85% of the brains mass… As well part of the forebrain is the hypothalamus, which controls many of the body's automatic processes such as eating and sleeping…
Connecting and integrating		A posting that connects different ideas to generate a synthesis, summary, conceptualization, or integrated solution	We think the sensory neurons, muscles, and the brain all help you prevent a burn. We think this because the sensory neurons feel that an object is to hot or warm. Then the sensory neurons send signals to the brain to move your hand (or other part of the body)… In conclusion, we think the sensory neurons, muscles, brain, and afferent and efferent nerves all help you prevent a burn…

Table 3 Processes by which the community co-generated structures about what the community should investigate

Processes	Teacher and student input to the reflective processes		Inquiry structures created/adapted
(a) Generating initial inquiry areas based on students' individual research questions	Teacher: identified the Human Body as the content area based on the school's curriculum; prepared 10 outdoor games involving various human body functions; prepared a collection of books about human body systems; facilitated whole class discussions to reflect on the outdoor games and share questions related to human body systems	Students: participated in the outdoor games to experience various body functions; shared experience and questions in the class discussion; listed their questions in notebooks and shared with peers; discussed connections among the questions to form wondering areas; formed four initial groups based on interest and created four big questions	individual research questions in science notebooks; four inquiry areas recorded on a chart paper: *"How do bone marrow, blood and veins work?" "How does the brain do its jobs*[SIC]?" *"How do muscles, bone, and vocal cords work?"* and *"How does your body react to radiation, acids and chemicals?"* four initial groups with four workspaces created in Knowledge Forum
(b) Conducting inquiry while elaborating and expanding the inquiry areas based on new emergent questions	monitored knowledge progress in the four areas; chatted with individuals and small groups about new questions generated from the ongoing inquiry; facilitated small group and whole class discussions to share new questions	conducted individual and group inquiry to address the focal questions; generated more specific questions; shared new emergent questions in classroom reflection and online; formed new groups to work on new topics	the "human body reaction" group updated their question as "How does the immune system work?" the "muscles, bones, and vocal cords" group updated their question as "How do parts of the throat and mouth work together?" three small groups formed; three inquiry areas added to the chart paper; three workspaces created in Knowledge Forum
(c) Developing specialized topics to guide and sustain students' advanced inquiry	monitored knowledge progress in all the areas of inquiry; modeled how to plan inquiry based on the specialized questions	identified overarching questions for specialized research; drew a map of the sub-questions (themes) they planned to work on; shared individual maps of inquiry in classroom talks and online	individual questions shared in whole class meetings and online; maps of sub-questions for specialized inquiry; an "Advanced Research" view in Knowledge Forum

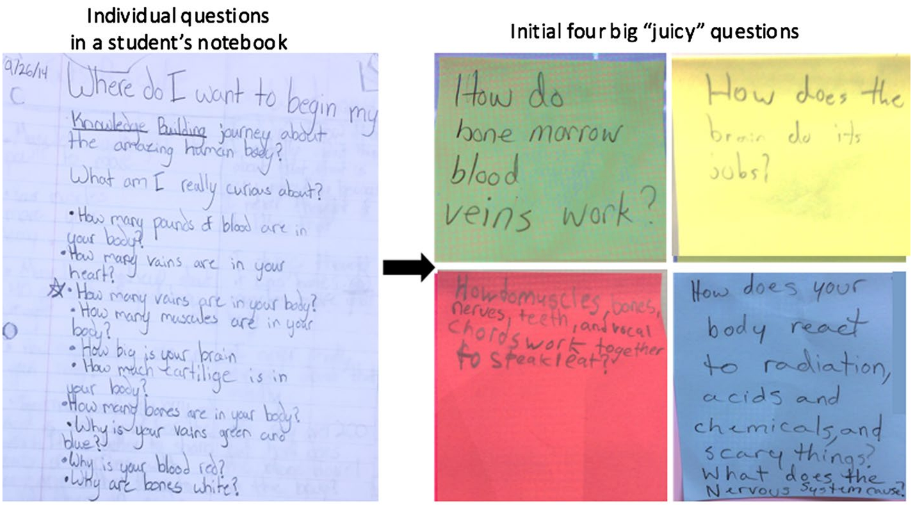
summarizes the participation of the teacher and his students in the reflective processes together with the structures formed and adapted. We further describe the detailed processes below, with detailed accounts of how the various elements of the structures were formed and, then, used by students and their teacher.

Co-generating initial inquiry areas based on students' individual questions

The teacher identified the human body systems as the science topic based on the school's curriculum. The human body inquiry began with a kick-off event in mid-September that included a series of outdoor activities. The teacher worked with two other Grade 5 teachers to design the activities with the goal of engaging student interest in and experiences with various human body systems (e.g. movement control, senses, memory). Each activity required students to use certain body parts to perform challenging tasks. Following the outdoor activities, a whole class reflection was organized in the classroom to share their experiences and questions. Students showed deep interest in the functions of the human body. The teacher also introduced students to a collection of books placed in the classroom related to various human body systems.

To consolidate student interest into shared areas of inquiry, the teacher asked students to reflect on "*What am I really curious about*?" Each student listed all the questions that she/he was curious about in the first page of her/his notebook (see an example in Fig. 2a). Most of the students wrote down approximately eight to ten questions. The teacher then suggested that each student select a question to start with: "*Where do I want to begin my knowledge building journey*?" Students reviewed their questions in their notebooks, marked questions they were most interested in, and then wrote them down on sticky notes.

The teacher collected the individual questions, read them one by one and posted them on the blackboard. He further asked for students' opinions about how to organize the sticky notes. Students proposed that the questions should be organized based on the connections.



(a) (b)

Fig. 2 Formation of the initial four big "juicy" questions

Questions about the same or related topics were placed in one section. For example, the teacher read the question "*What is bone marrow?*" He placed it on the board and asked students to find questions that were close to it. The teacher then read the question "*Why is some blood blue?*" Students commented that it was about blood, not about bones. The teacher read the question "*How does bone marrow make new blood?*" Students realized that the topics about bone marrows and blood were actually connected, eliciting further discussion about the specific connection. Students suggested that another question, "*How many veins are in your body?*" was also related to *blood*. The above four questions were clustered together as an area of inquiry, with the four students formed into an emergent group to work in this area. Through similar processes, the community identified three other areas of inquiry, each of which became the focus of a temporary small group. Then the teacher suggested the four small groups meet to develop a big "juicy" question as their overarching focus. For example, the small group working on blood and bone marrows generated the question of "*How do bone marrow, blood, and veins work?*" And the other three big juicy questions generated were: "*How does the brain do its jobs?*" "*How do muscles, bones, nerves, teeth, and vocal chords work together to speak and eat?*" "*How does your body react to radiation, acids and chemicals, and scary things*?" (see Fig. 2b) To highlight these big "juicy" questions to the whole class, the teacher listed the four big questions on a large chart paper, which was hung on a wall in the classroom. Four corresponding views (workspaces) were set up in Knowledge Forum to support the online knowledge building discourse.

Conducting inquiry while further elaborating and expanding the inquiry areas

Guided by the initial "juicy" questions, students worked with their peers to carry out research using books, websites, and models. In their science class, members interested in each "juicy" 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 findings. As the inquiry proceeded, students generated more specific questions. For instance, the three students who worked on "*How does your body react to radiation, acids and chemicals, and scary things*?" shared their initial research. As examples of the human body reactions, they mentioned the various allergies that their family members had, triggering their interest in how allergies work. As an agreement, they planned to narrow down their broad inquiry about the human body reactions to allergies. The three individual students tried searching online to see what information they could find. A member found a video explaining the causes of allergies, from which she took notes in her notebook. Another student read a few webpages explaining "*How children might get allergies from their parents*?" The three students shared their information and generated three specific questions as their focus: *What are allergies*? *Why do we get allergies*? *How can we protect ourselves from allergies*?

The teacher reviewed student ideas and questions in the four areas of inquiry as he talked with individuals and small groups and read their online postings. Groups that had new insights or deep questions were invited to share their progress and questions at whole classroom meetings. Through sharing progress and reviewing their new questions, students developed updated understandings of the inquiry foci, leading to the reframing of some of the inquiry areas. For example, after working on allergies for a while, the students reframed their research focus as "*How does the immune system work*?" Students working on “muscles, bones, and vocal chords” also developed a more specific focus on “*How do parts of the throat and mouth work together*?”

The updated foci and questions continued to guide student knowledge building actions in the classroom and online. For example, the updated inquiry areas and questions were used to focus and organize whole class meetings to share and deepen knowledge related to each “juicy” question. Collective meetings were organized to discuss knowledge progress about the blood and heart in late October, about the brain in early November, about the throat and mouth in mid-November, and about allergies in early December.

While there were small groups developed based on the inquiry areas, students were free to interact with different peers as needed or work on other areas related to their research. Based on the updated inquiry areas and “juicy” questions, the teacher created a two-dimensional area-student mapping chart (see Fig. 3), which was hung on the classroom wall to help students plan and keep track of their participation on a daily basis. Student names were listed in the columns following the “juicy” questions. In the beginning of every science class, each student indicated the inquiry area(s) she/he planned to work on by placing a small magnet next to the inquiry question(s). They were also encouraged to write new specific questions on sticky notes put under any of the existing “juicy” question or suggest new research areas and directions. Blank rows were left on the chart for possible new research areas. For example, two students in the brain group were fascinated about dreams. After a discussion with the teacher, they proposed sleep as the fifth area of inquiry, which was phrased as “*What’s happening in your body while you sleep*?” Several students who had been working on the other areas became interested in this new area too. Through similar processes, two additional “juicy” questions were added to the chart, each with an emergent group formed: “*How does the digestive system work?”* and “*How does the respiratory system work?*” Students who worked on new questions but hadn’t formed a small group and a big question yet moved their magnets to the last row on the chart (see Fig. 3).

Students continued their inquiry with the seven “juicy” questions until February 2015. Each student engaged in research while generating deeper and more specific research questions in their notebooks. For example, a student studying the brain generated the following research questions: “*How do the nerves catch signals from the*

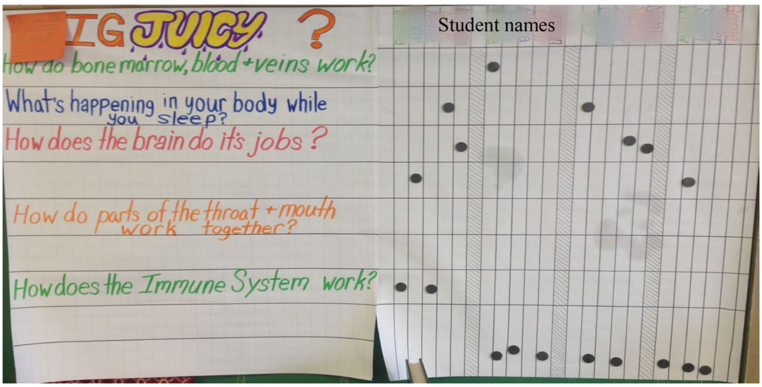


Fig. 3 A mapping chart to keep track of student participation in the collective inquiry areas

brain?" "*What side effects happen to your body when you get a concussion?*" Another student studying the brain continued his journey of research on colorblindness driven by the following questions: "*What's the cause of colorblindness and why does it affect our vision*?" "*Why does colorblindness happen and affect people*?"

Developing specialized directions for more advanced inquiry

By late February, students had carried out extensive work in the seven inquiry areas that they had formulated, with new knowledge progress shared in their face-to-face meetings and Knowledge Forum notes. Building on this foundational knowledge, students began working on more specialized problems of the human body that related to their personal experiences. For example, a girl, who often got sick in winter began to research how doing exercise helps our bodies. Another girl, who broke her leg during the winter break, got interested in "How do bones heal?" Noticing the new specialized interests developing among his students, the teacher envisioned that the community could move into a new phase of research where students engaged in more advanced inquiry. Therefore, he facilitated a whole class meeting for students to share their ideas about where the community should go next. Students shared their research directions and questions at this meeting.

After this meeting, the teacher worked with the students to plan out their specialized/advanced inquiry based on how the community approached their initial "juicy" questions. The teacher modeled using a mind map to approach a big question through generating sub-questions and inquiry directions. And, then, each student wrote down their own advanced inquiry question in the center of a piece of paper and added branch questions as possible directions. Figure 4 shows the map of a student who worked on mitochondrial disease. The focal question for her advanced inquiry was "*What is the mitochondrial disease*?" She also developed a series of branch questions to guide her work on this topic, such as: "*How do you get it?*" "*What would happen to your cells?*" "*How can you eat when you have mitochondrial (disease)*?" A new *view* (workspace)

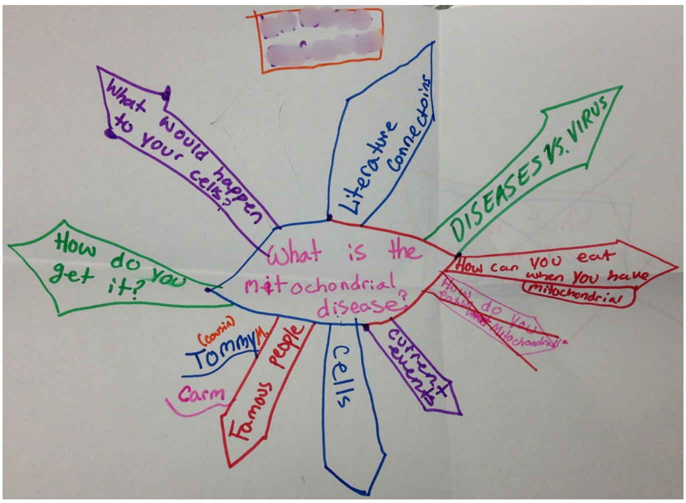


Fig. 4 A student's map of inquiry directions focusing on her research question about mitochondrial disease

was created in Knowledge Forum named "Advanced Research." Student shared their mind maps in this view and used the maps to guide their specialized inquiry from late March to mid-June.

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

The analysis of the classroom videos and observation notes identified the reflective processes by which the community generated and adapted a "research cycle" model to inform members' inquiry actions. These processes are summarized in Table 4 and elaborated below.

Reflecting on intuitive inquiry experiences to develop a shared sense of the research journey

Students began their inquiry about the human body in mid-September. Without teacher-specified inquiry procedures, students worked on their focal questions based on their prior experiences with science learning and information collection. Notably, students applied various reading strategies (e.g. note taking) acquired in their previous classes as they searched books and other materials for information. The teacher observed student research activities in the classroom and occasionally asked questions to help students further 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 damage in mid-October, students engaged in active responses to one another's ideas to offer further information, make connections, and raise deeper questions. The teacher seized the opportunity to facilitate a reflection on how to conduct inquiry. He shared his observation of how student ideas had grown in this discussion and shared a metaphor that research is like a journey. He asked students to reflect on their own journey in terms of where they were now and where to go next in their research. The following two guiding reflection questions were written on the blackboard, with examples taken from students' notebooks for each:

> (Q1) Once you have learned a lot of fascinating information, what has begun to happen?
>
> *What has begun to happen is that we are starting to form opinions, and hypotheses about our topics. While we keep getting more questions, we try to answer them. You eventually get too many questions and not enough answers. So we have some more work to do to answer those questions.*
> (Q2) What are the next steps in a research journey?
> *The next steps in a research journey are to find more information about our key topics, then eventually try to find a way of sharing them. That is at least what you wish do when you have just done a lot of research on something.*

Students shared their responses in their small groups and, then, as a whole class. The main points were recorded by the teacher on two pieces of chart paper (see Table 5 for a summary). As Table 5 suggests, the students' reflection 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.

Table 4 Processes by which the community co-generated inquiry structures about how to do research

Processes	Teacher and student input to the reflective processes		Inquiry structures created/adapted
(a) Reflecting on intuitive inquiry experiences to develop a shared sense of the research journey	Teacher: monitored students' inquiry actions and knowledge progress; supported students' reflection on inquiry actions and plans; facilitated a whole class reflection on their journey of research	Students: carried out inquiry based on previous experience; reflected on their research journeys in notebooks; contributed to whole class reflection on their journey of research	implicit structures of inquiry from prior learning experience; individual research journeys in science notebooks; a shared sense of research as a continual journey reflected on the chart paper
(b) Co-generating a more systematic representation of the research cycle through small-group reflection	monitored students' progress in light of the continual research journey; supported small group reflection to create research cycles; reminded students to use and revisit their research cycles in their subsequent learning	shared individual research journey with peers; participated in group discussion to create research cycles; conducted inquiry in focal areas guided by their research cycles; refined group research cycles based on research experience gained	initial small group research cycles; refined small group research cycles
(c) Creating a collective research cycle model based on refined research cycles from small groups	monitored students' inquiry progress; facilitated a whole class reflection to generate a collective research cycle	shared small groups' research cycles; participated in a whole class reflection to create the collective research cycle according to accumulated inquiry experience	a collective research cycle chart hung on the classroom wall
(d) Ongoing adaptive use of the inquiry structures by individual students	engaged in noticing and highlighting of strong inquiry practices; modeled how to plan and monitor their inquiry using the research cycle	planned and monitored group and individual inquiry with the collective research cycle; adapted the collective research cycle to guide research	strong examples of research cycle use; personalized models of research cycles

Table 5 Student reflection on where they were and where to go next based on the teacher's two guiding questions

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…

Co-generating a more systematic group representation of the "research cycle"

With a shared sense of inquiry as a deepening journey, students continued to carry out their inquiry and knowledge building discourse in their focal areas. With richer experiences accumulated in the inquiry processes, the teacher suggested that each group reflect on their group research journey and create a more systematic research cycle to help guide their daily research actions. Below is an excerpt from the discussion of four students working on the brain where they reflected on the components of their research cycle:

S1(Student 1): So a research cycle is a circle? So what do you think is the first? Find a fact?

S2: Find a topic, or topic…
S3: No, this is a cycle! [erases the small circle in the middle and drew a larger circle]
S2: Find a question?
S3: No, find a fact about your topic.
S1: Okay, and we will do arrows [draws a small cycle on the large cycle and uses arrows to show the steps]. Okay. And then what's that?
S2: Then find a question?
S4: Make a question about your fact?
S3: Share?
S2: Like on Knowledge Forum……
S1: [writes "share with people" on the poster] and then, how about "making a theory?"
S2: In your notebook or on Knowledge Forum…
S1: Okay, how to spell theory?
S3: T-H-E-O-R-Y.
S1: Okay, what's next?
S4: Research about your question…Yeah. [S1 writes on the poster]
S1: Okay, now what? Find a fact about your topic, make a question, share with people, and make a theory…so what's the, what's the…scientific method? What's the next?

S4: Okay, so share your information on Knowledge Forum… [S1 writes on the poster]
S2: Start again?
S4: And then, make a question, get a fact……what should it be?
S2: Start again.
S3: Yeah, it's a cycle.

In the above discussion, the students proposed components of inquiry actions and ways to organize them. Some of the components were adopted and written on the poster; others were rejected or rephrased by other members with agreement. The students reflected on their own inquiry process in light of their sense of the authentic practices of scientists, such by asking: "*What's the…scientific method*?"

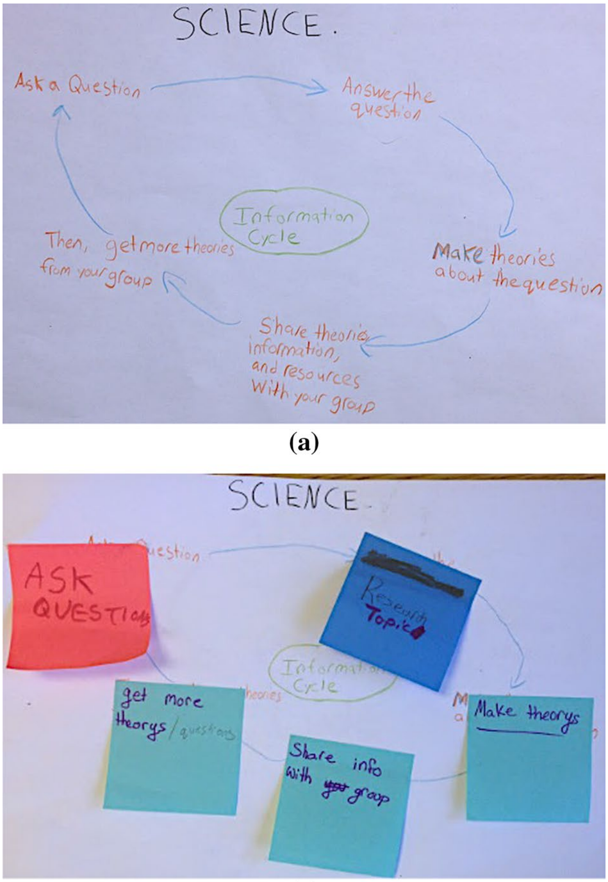
The four small groups' initial "research cycle" models included several shared components: *asking a question, collecting facts, answering the question, making theories, sharing information and resources, generating more theories, building onto theories, and finding new questions*. The teacher reminded his students that the actions in their cycles were not linear or fixed, and that they could update the research cycles whenever needed. Each small group referred to their own model to plan their work and decided what they needed to do for deeper inquiry. It was also used by the teacher to understand where each individual or small group was in their inquiry process and support their planning. Below is an excerpt from a conversation between the teacher and a few students who were researching the throat and mouth:

T: So while we are here [the throat and mouth area], where are you? … kind of…put yourself in your cycle that you have here? [points to the research cycle created by this group]

S1: I would say about…here [points to "Making theories"]
T: So you are somewhere between "*Making theories about the question on KF*" and… you have some information that you can make some theories. That's great. So make some theories that you share in the (classroom) meeting. So where are you guys seeing yourself in this cycle?
S2 and S3 (talk together): Making theories…
T: So you are all with the similar pace…. Great! Maybe you guys can make theories and then…meet…
S2: So we can make a better theory?
T: Yeah! Like something that you can…say…like… "Hey, we have the same theory…" So I think you guys are more or less on the same page…Awesome!

Around mid-December, students worked as groups to re-visit and refine their initial research based on their accumulated experience and updated understandings. 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 Fig. 5a). They generated an updated cycle (see Fig. 5b) 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 their theories.

Fig. 5 The initial (**a**) and refined (**b**) research (information) cycle from a small group



(a)

(b)

Creating a collective research cycle model based on refined research cycles from small groups

In January, with progress made in their focal areas of inquiry, students shared their knowledge through whole class meetings and interactions in Knowledge Forum. The original groups disbanded or reformed as students started to work on new topics of research. The teacher suggested that the whole class synthesize the research cycles created/refined by the groups into a collective model that everyone could use to guide their research. Through a whole class discussion, students reviewed all the small groups' models, identified common components, and suggested additional components, leading to creation of a collective research cycle that had seven components (Fig. 6). In the above discussion, the teacher challenged students to rethink about their inquiry actions and rephrase their actions using 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*?'" The collective research cycle chart was hung on the wall as a guiding tool for students to plan and conduct their specialized inquiry from February to June.

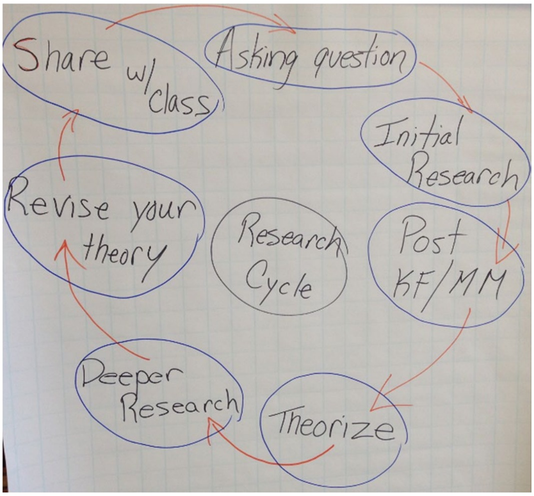


Fig. 6 The collective research cycle model generated by the community

Ongoing adaptive use of the inquiry structures by students

The structures generated through the above reflective processes, including the initial framing of the research journey, small group research cycles and the collective research cycle, assisted students as they planned their research and reflected on progress. The teacher modeled reflective monitoring of inquiry practices using the research cycles and purposefully identified examples of strong practices. For example, the teacher noticed that a student was taking notes in her notebook to summarize new information and generate new questions and theories (see Fig. 7). He advertised this practice to the whole class, by saying:

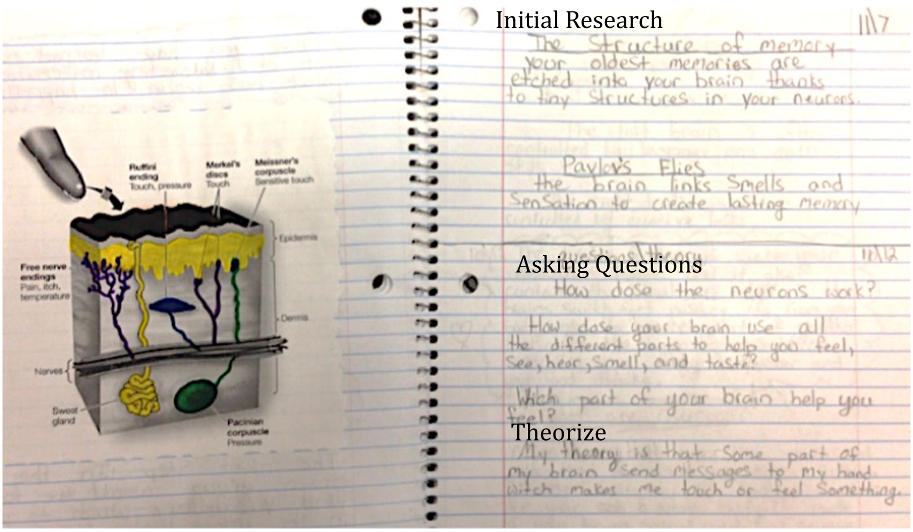


Fig. 7 A student's note-taking aligned with the actions in the research cycle

> 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.

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

In what ways did students use the "research cycles" to deepen their inquiry and support their participation?

We conducted further analyses of how students used the "research cycles" to guide and support their inquiry. Based on the interview data, we found that all of the interviewed students commented that the research cycle was helpful in guiding their knowledge building process. Six of them were able to recall all the exact components in the cycle and describe individual or small group inquiry processes aligned with the cycle. A few of the students commented that the research cycle worked "pretty well," so they usually followed the components in order as they investigated different research topics. For example, a student mentioned: "*All of the topics I did, I always did that order…*" Some of the students used the cycle flexibly in different situations or used the collective cycle to develop their own cycles for deeper research. When a certain component was unnecessary for their research, they would "*kick that part out*." As a student doing specialized inquiry on kinetics in speed skating reflected, because her topic was so specialized, she could not get much input from her peers and needed to spend most of her time collecting information and doing initial research. Another student said: "*I would use the cycle to guide me…But I would use just like baseline…I have my own research cycle (created based on the collective research cycle) …*" Students also considered different factors that might affect how the research cycle would be used, such as shorter cycles for smaller topics; longer and more complex cycles for broader questions.

As noted above, generating deeper and more advanced inquiry questions was essential to formulating the research directions. It was also a major component in the research cycles. Therefore, we traced student research questions written individually in September and again in May and coded the questions using the "structure-behavior-function" framework (see Fig. 8). The proportions of students' questions differ significantly between September

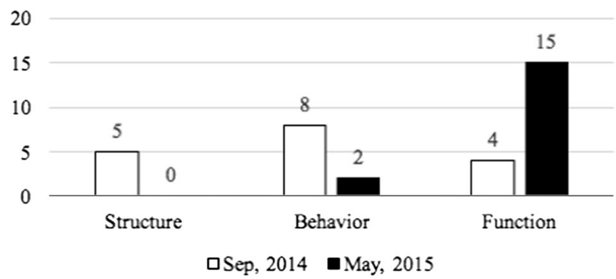


Fig. 8 Different types of student individual research questions in September and May

and May ($\chi^2 = 14.97$, $df = 2$, $p = 0.001$). In May, students generated more research questions, all of which went beyond factual information about the body parts (structure) to explain how the various body parts achieve their functions or result in malfunctions.

To trace student inquiry work reflected in their collective discourse, we further analyzed their online discourse contributions as related to the various actions highlighted in the "research cycle." We chose the date when students began to negotiate their small group "research cycles" as the cutting point for comparison, as students spent approximately equal amounts of time online before and after this point. We examined the various types of contributions and traced changes from before to after the negotiation of the research cycle. As Table 6 shows, before the construction of the "research cycles," the most compelling types of online contributions posted relatively broad explanatory questions about the body systems, generated intuitive explanations, and refined the explanations. After the negotiation of the "research cycles" that highlighted a diverse range of specific knowledge building actions, students had a larger number of posts raising idea-initiating questions and idea-deepening questions, elaborating ideas using referential sources of information, using evidence to support or challenge ideas, providing alternative explanations, and connecting and integrating ideas to develop coherent understandings.

Discussion

To demystify how student-driven, open-ended, and dynamic process of inquiry may be sufficiently organized and supported, this study examined the reflective structuration processes in a Grade 5 community. Deepening our prior study (Zhang et al. 2018), the findings of the current study provided a more elaborated account of how the students and their teacher worked together to co-construct shared inquiry structures to shape and guide their ongoing knowledge building interactions over a school year. We discuss the findings in light of the three key points of the reflective structuration framework.

Table 6 Students' knowledge building contributions in Knowledge Forum

Contribution type	Before constructing the initial group research cycles	After the formation of the initial group research cycles
1. Questioning		
Factual question	8	8
Explanatory question	45	18
Idea initiating question	17	48
Idea-deepening question	24	70
2. Theorizing/explaining		
Intuitive explanation	110	114
Alternative explanation	13	34
Refined explanation	31	29
3. Evidence	18	88
4. Referencing sources	24	167
5. Connecting & integrating	1	7

Students can co-construct inquiry structures with their teacher as they build domain knowledge

Consistent with our previous studies (Tao et al. 2015; Zhang et al. 2018), the findings of this study suggest that the fifth-graders were able to work with their teacher to construct collective inquiry structures as they carried out collaborative efforts to build and deepen their scientific knowledge. They constructed an evolving set of structures to frame what their community should investigate for deeper inquiry and how the inquiry process should be effectively approached. To structure what the community should investigate, the community created and adapted a list of shared inquiry areas, represented as big “juicy” questions, with students in each area generating more specific questions to guide their directions of inquiry. The shared areas of inquiry were formulated and elaborated over time through student individual monitoring of ongoing inquiry and reflective conversation about what they needed to research. The structures evolved from the overarching focus on human body systems introduced by the teacher, to forming an initial list of four overarching questions rising above students’ diverse interests and questions, elaborating deeper inquiry foci and new areas (e.g. the immune system and dreaming) that emerged from individual and collaborative work, and developing specialized directions of inquiry. These shared structures of inquiry were represented and highlighted using classroom artifacts to guide student attention and participation. Individually, each student moved a magnet on the collective questions chart to position his/her daily research in the context of the community’s inquiry directions. At the small group level, flexible groups were formed based on the “juicy” questions involving members who had shared interests. Collectively, the community organized whole-class meetings as needed focusing on advances and issues that emerged in each inquiry area.

As the structure to frame the process of inquiry, the community co-constructed and adapted a research cycle model through individual monitoring and reflective conversations. Students monitored their ongoing inquiry actions to reflect on their personal research journeys and formulate group research cycles, which were used to guide student inquiry in the following weeks. With accumulated experience, students then reconvened as a whole community to generate a collective research cycle model based on the small group research cycles. Students referred to components of the research cycles to communicate their work and reflect on how they might deepen their inquiry.

The two types of structures to frame what should be researched as well as how to research appeared mutually supportive of each other, with a shared focus on idea improvement through progressive problem solving (Scardamalia and Bereiter 2006). Efforts to build shared structures about the inquiry focus and directions involved framing initial “juicy” questions and generating deeper and more elaborated questions as the inquiry advanced. Reflecting on their shared experience with the progressive journey of inquiry, students generated the research cycles that highlighted inquiry as progressive problem finding for continual theory refinement. Interestingly, the components of the student-generated research cycle showed a high-level consistency with the epistemic operations for progressive idea improvement identified by researchers (Bielaczyc and Ow 2014).

There is a temporal interplay between the two layers of construction

The Grade 5 community appropriated structures from its prior practices and from their school's context to focus and guide members' initial exploratory inquiry to build scientific understandings, which gave rise to further structure building and adaptation for deeper inquiry. The co-constructed structures served to capture emergent directions and processes of inquiry in the community, and then became a guiding resource to inform and support members' efforts for further inquiry. For instance, students used the research cycles adaptively to guide their personal work and reflected on their inquiry progress in light of the components of their research cycle (see Fig. 7). The research cycle supported their search of deeper questions to guide their inquiry (Fig. 8) and informed their contributions to the knowledge building discourse. In reflection of the components of the research actions, their online discourse involved asking questions to deepen existing ideas and initiate new ideas, elaborating ideas using information sources, collecting evidence, and providing alternative explanations (Table 6). The co-constructed structures helped to inform students' knowledge building directions and actions in this yearlong inquiry.

Co-constructing inquiry structures works as a means to foster student agency and collective responsibility

Over time and with the co-constructed structures mediating the community's inquiry practices, traditional roles of the teacher to guide classroom processes can be largely distributed to the community. In this study, the teacher played various important roles in the co-construction, adaptation, and reflective use of the inquiry structures. These included mediating the adoption of the human body as the science topic, seeding potential inquiry directions through reading materials and activities, facilitating reflective conversations to frame "juicy" questions, capturing and reifying the structures emerged using online and classroom artifacts, modeling how to organize focal research questions and sub-questions, ongoing monitoring of inquiry practices, and supporting students' meaningful and adaptive use of the structures. The teacher input and scaffolding was directed toward helping students to develop their own agency and control over the knowledge building process in connections with (but not limited by) the expectations of the school's curriculum. Students took on high-level responsibilities as they engaged in the reflective monitoring and conversations to formulate shared inquiry goals and frame the inquiry processes. The co-constructed structures were then used by students to direct their inquiry, deepen their discourse, and reflect on progress, fostering intentional advancement of their community's knowledge.

Limitations

Notably, this study has several limitations. First, the analysis focused on depicting a whole picture of the how the community co-constructed the inquiry structures to sustain its knowledge building over a school year. In the current study, we did not have the data needed to look into students' moment-to-moment decision making in relation to their inquiry directions and research cycles. Future research and analysis need to provide more detailed analyses of students' interactions that contribute to the formation and evolvement of the structures. Second, the analysis of the role of the co-constructed structures relied on the tracing of question types and discourse patterns across time periods; this could not tease out the impact of student experience on the refinements of their inquiry and discourse contributions. The impact of the co-constructed structures was examined in the aforementioned study using a cross-classroom comparison design (Zhang et al. 2018). Similar to the findings of the current study, the classroom engaged in reflective structuration showed more active and connected contributions to the knowledge building discourse. Finally, further research also needs to investigate what kinds of co-constructed structures of inquiry may exist in broad knowledge building communities, conduct more systematic coding of various elements of the structures, and conduct more in-depth analysis of student uses of the structures in individual, small-group, and collective work.

Conclusions and implications

This study provides an elaborated account of how the grade 5 community co-constructed shared structures of inquiry to support and sustain its knowledge building practices over time. Extending our prior work that analyzed co-constructed structures to frame the inquiry focus and directions (Tao et al. 2015; Zhang et al. 2018), the results additionally examined the construction of process-oriented structures in the form of research cycles. The co-construction of inquiry structures involved working with existing structures (e.g. curriculum area) appropriated into the community and went through further structural elaboration and adaptation to frame/reframe what the community should research and how to conduct inquiry. Structure-bearing classroom artifacts were generated and used to make the structures visible to the community. The structures were then used as a means to monitoring personal and collective inquiry practices and deliberating deeper inquiry actions, as reflected in student personal work and collaborative discourse. As their ongoing knowledge building actions and interactions led to deeper inquiry opportunities, members revisited their inquiry structures for further refinements.

As a conceptual implication, this research highlights the importance of co-constructed inquiry structures in learning communities. Such structures provide a socio-epistemic mechanism to address the two competing needs that are both essential to sustaining inquiry and knowledge building practices: to encourage student high-level agency as the course of the inquiry unfolds, and at the same time, to incorporate support structures that orient students about what they need to research and how to carry out deep inquiry. Co-constructing inquiry structures helps to empower student control over the unfolding courses of inquiry and at the same time hold students accountable for making purposeful and responsible contributions. Inquiry structures in a community are progressively generated and elaborated over time in light of the evolving knowledge of the community,

As a practical implication, the reflective structuration approach can be adopted and developed as a new classroom strategy to implement long-term, collaborative inquiry and knowledge building without extensive pre-scripting. High-level issues, such as what to investigate, through what processes, by whom, can be co-structured by students with their teacher as the inquiry unfolds over time. To support the co-construction of inquiry structures in sustained knowledge building, we designed a timeline-based, collaborative, inquiry-structuring platform: Idea Thread Mapper (ITM) (Zhang et al. 2018). The core features support students' reflective efforts to capture emerging directions in extended discourse, formulate unfolding strands of inquiry, and track students' collaborative roles in the strands of inquiry. We are upgrading ITM to further include process-oriented structures and incorporate learning analytics to trace the various inquiry actions and contributions, such as those analyzed in this study.

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