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# Epistemic Agency for Costructuring Expansive Knowledge Building Practices

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**Abstract**

As a hallmark of authentic science practices, students need to enact epistemic agency to shape/reshape the key aspects of their inquiry work as a collaborative community. This study elaborates an emergent temporal mechanism for engaging students' epistemic agency: "reflective structuration" by which members of a classroom community co-construct ever-evolving inquiry directions and group structures as their collective inquiry work proceeds. Using an interactional ethnography method, we examined how students (*n* = 22) in a Grade 5 classroom co-constructed shared inquiry directions and flexible group structures to guide their sustained inquiry about human body systems over seven months supported by a collaborative online environment. Rich data were collected to trace the work of the eye inquiry group as a telling case. With their teacher's support, students took agentic moves to construct an evolving set of wondering areas as a way to frame what their whole class needed to investigate. Flexible groups, such as the eye inquiry group, emerged and evolved in the various areas, leading to progressively deepening inquiry and extensive idea exchanges among students. Implications for research and practice are discussed.

**Keywords**: authentic science practices, collaborative learning, epistemic agency, knowledge building, reflective structuration

## 1. Introduction

To prepare students for productive work and social life in a constantly changing environment, education needs to cultivate creative and adaptive knowledge practices across disciplinary areas (Hakkarainen, 2009; Pendleton-Jullian & Brown, 2018; Sawyer, 2015; Scardamalia & Bereiter, 2014). In science education, recent research and reforms highlight the need to develop authentic science practices (National Research Council, 2012; NGSS Lead States, 2013). In line with how knowledge is constructed in the real world, students are expected to work as active sense-makers and "doers" of science to figure out how the world works (Berland et al., 2017; Manz, 2015; Schwarz et al., 2017). Through this process, they not only learn disciplinary concepts and skills but also become legitimate participants in the science enterprise including its social, epistemic, and material dimensions (Engle & Conant, 2002; Ford and Forman, 2006; Lehrer & Schauble, 2006).

To cultivate authentic science practices in the classroom, educators need to engage students' epistemic agency. Epistemic agency can be defined as "students being positioned with, perceiving, and acting on, opportunities to shape the knowledge building work in their classroom community." (Miller et al., 2018, p. 6) Dominant practices of science teaching often position the teacher as the only epistemic agent in a classroom, who promotes students to complete predefined tasks and curricular activities in preset timeframes (Chinn & Malhotra, 2002; Seitamaa-Hakkarainen, 2022; Stroupe, 2014; Varelas et al., 2015). To create opportunities for students to work as epistemic agents, researchers call for efforts to develop more dynamic and expansive classroom configurations that open up opportunities for student-driven inquiry and creative imagination (Duncan & Chinn, 2021; González-Howard & McNeill, 2020; Gutiérrez &

Calabrese Barton, 2015; Ko & Krist, 2019; Tao & Zhang, 2021). As a core challenge, the field needs to better understand how student-driven, open-ended inquiry processes can be organized and guided in the classroom in a manner that engages student epistemic agency.

The current study elaborates an emergent temporal mechanism for engaging students' epistemic agency: "reflective structuration" by which members of a classroom community co-construct ever-evolving inquiry directions and group structures as their collective inquiry work proceeds. In this paper, we first review the literature on the dynamic nature of science practices and knowledge building, and then propose reflective structuration as our conceptual and analytical lens. We analyze reflective structuration in a Grade 5 science classroom that studied human body systems over seven months. The results provide a thick description of how students co-constructed collective inquiry goals and flexible groups as their work evolved.

**1.1 Literature Review on Expansive Knowledge Building Practices**

Science learning entails learning the authentic practices of scientific knowledge construction by engaging in classroom activities that reflect important aspects of professional science (Chinn & Malhotra, 2002; Engle & Conant, 2002; Ford & Forman, 2006; Hutchinson & Hammer, 2010; Lehrer & Schauble, 2006). Real-world knowledge building practices unfold as a dynamic process to address ever-evolving challenges and unknowns (Knorr Cetina, 2001). Therefore, knowledge creation teams work with the emergent, uncertain and ever-unfolding nature of creative processes, encourage diverse ideas and leadership among all participants, and leverage flexible idea interaction and self-organized collaboration (Bielaczyc & Collins, 2006; Gloor, 2006; Sawyer, 2015). Pendleton-Jullian and Brown (2018) use the metaphor of white-water kayaking to describe creative knowledge work in a hyper-connected world: Instead of pushing forward along a fixed path, knowledge builders, like kayaking teams, need to constantly read the evolving context and reposition their center of gravity in order to participate in and shape the flow of knowledge around them.

To cultivate such science practices, researchers call for efforts to design more open and expansive classroom configurations that foster student agency in shaping and re-shaping their learning processes and pathways (González-Howard & McNeill, 2020; Gutiérrez & Calabrese Barton, 2015; Ko & Krist, 2019; Miller et al., 2018; Tao & Zhang, 2021). Instead of merely completing predefined inquiry tasks and procedures, students have the opportunities to chart the course of inquiry and navigate the uncertainty in science practices (Blanchard et al., 2010; Chen et al., 2019; Engle, 2006; Duschl, 2020). As research shows, by opening up the curriculum and allowing students to grapple with scientific uncertainty in the classroom, educators can enable more meaningful science practices among students (Manz, 2015; Manz & Suárez, 2018). Students work on ambiguous problems, make decisions about what to investigate and how to design their investigations, generate and work with diverse explanations, participate in authentic knowledge-building dialogues, and engage in personal and shared reflection on knowledge advances and gaps that inform future inquiry (Berland & Hammer, 2012; Berland & Reiser, 2011; Ford & Forman, 2006; Lehrer & Schauble, 2006; Varelas et al., 2007; Tao & Zhang, 2021).

In this study, we draw upon the Knowledge Building pedagogy to investigate ways to engage student epistemic agency for expansive science practices. "Knowledge Building pedagogy is based on the premise that authentic creative knowledge work can take place in school classrooms – knowledge work that does not merely emulate the work of mature scholars or designers but that substantively advances the state of knowledge in the classroom community and situates it within the larger societal knowledge building effort." (Scardamalia & Bereiter, 2014, p. 434). Working as a collaborative community, students engage in sustained inquiry and discourse to advance the state of their community's knowledge: their *collective knowledge* as a social product (Scardamalia, 2002; Scardamalia & Bereiter, 2014). Extensive research has investigated the socio-cognitive processes of knowledge building associated with collective knowledge progress and personal growth in 21$^{st}$ century competencies (Chen & Hong, 2016; Tan et al., 2021).

The Knowledge Building pedagogy includes a set of design principles and features, which support student agency for expansive science practices. Below we highlight a few principles and review the related research works and needs. First, student knowledge building is framed as a process of *progressive problem solving for continual idea improvement* (Scardamalia, 2002). Authentic problems arise from student efforts to understand the world. To solve the problems, students generate tentative ideas, engage in sustained inquiry, and continually improve their ideas toward deeper understanding and better coherence. As progress is made in figuring out existing problems, students discover new or deeper problems that need to be addressed, driving deeper inquiry and discourse in the classroom (Scardamalia & Bereiter, 2014; Zhang et al., 2007). This core feature supports an expansive framing of ever-deepening inquiry (Engle, 2006). Knowledge builders do not merely enact repeated procedures to accomplish given tasks but continually shape and reshape their collective inquiry as their knowledge is advanced over time (Knorr Cetina, 2001; Scardamalia & Bereiter, 2014).

Second, students take *epistemic agency* over the unfolding knowledge goals and processes. Epistemic agency involves students' personal and collective responsibility for charting the course of sustained inquiry and knowledge advancement (Scardamalia, 2002; Scardamalia & Bereiter, 1991). In the classroom, students contribute to high-level decision-making about their knowledge work, including decisions normally left to the teacher such as long-range goals, inquiry strategies, social arrangements and criteria of success. Several researchers have investigated epistemic agency as a key feature of authentic disciplinary practices in science and beyond (Damsa, 2010; Miller et al., 2018; Stroupe, 2014). Their research elaborated on the various dimensions of epistemic agency, including (a) knowledge-related epistemic moves to produce new ideas and questions, push and "pull" peer's ideas, advance collective discourse and organize ideas in a way that creates the basis for further epistemic endeavors; and (b) process/participation-related moves, such as norm-building moves to ascribe agency and ownership over ideas, projective actions to shape future courses of collective action, regulatory efforts to coordinate personal and group processes, monitor progress and overcome challenges (Damsa, 2010; Stroupe, 2014). Beyond self-regulated efforts to direct and improve their learning, researchers underline students' high-level agency in changing the shared structures and conditions that constrain and support their actions in a community (Stroupe, 2014). Further research is needed to provide a clearer account of how such epistemic agency may be enabled and enacted in the classroom.

Third, knowledge building requires *collective responsibility for collaborative knowledge advancement* (Scardamalia, 2002). Students participate in collaborative interaction and knowledge-building discourse that mirror the discourse of real-world knowledge-creation teams and organizations. As Dunbar (1997) documented, productive science teams engage in distributed reasoning and discourse, in which members continually use peers' contributions as the input to further cognitive operations. A series of sustained discursive interactions may lead to new and often unexpected advances that cannot be attributed to any individual member. Research on knowledge-creation teams demonstrated the power of improvisational discourse and self-organized collaboration, which support the cross-fertilization of diverse ideas and expertise (Chatzkel, 2003; Gloor, 2006; Sawyer, 2007, 2015; Wageman et al., 2012; Williams & Yang, 1999). While collaborative learning is increasingly used to support student inquiry, educational practices often favor scripted collaboration in fixed small groups (Fischer et al., 2013; Kirschner & Erkens, 2013). In each small group that remains stable during an inquiry activity, students act in line with their assigned roles (e.g., source searcher and summarizer) to work on collaborative tasks (De Wever et al., 2008). To explore more dynamic collaboration for knowledge building, we conducted a three-year design experiment in a Grade 4 classroom (Zhang et al., 2009). Students of each year worked as a collaborative community to study optics supported by an online environment for knowledge building: Knowledge Forum (KF) (Scardamalia & Bereiter, 2014). The data analysis demonstrated increasingly productive collaboration and knowledge advancement corresponding to three designs: fixed specialized-groups in Year 1, interacting groups in Year 2, and opportunistic collaboration in Year 3.  For opportunistic collaboration, students formed collaborative groups based on shared interests and needs, and further reformed their group structures over time as their inquiry brought forth new problems and knowledge connections. Among the three designs, opportunistic collaboration was most productive in fostering students' collective responsibility, interactive idea build-on, and deep understanding (Zhang et al., 2007, 2009). Building on this study, Siqin et al. (2015) further examined fixed versus opportunistic group collaboration in a college class, showing similar results in favor of opportunistic collaboration. Several studies investigated how students enact spontaneous roles based on emergent needs and situations (Heinimäki et al., 2021) and engage in cross-boundary interaction between different groups and classroom communities (Rienties et al., 2018; Yuan & Zhang, 2019; Zhang et al., 2020). To support flexible collaboration, researchers are also exploring new technology designs to trace student interactions and guide group formation (Bodemer et al., 2018; Tsovaltzi et al., 2019). To inform such design efforts, deeper research is needed to understand the temporal process of opportunistic collaboration and ways to sustain such processes.

With the above features, Knowledge Building pedagogy provides a supportive approach to implementing expansive science practices and fostering student epistemic agency. However, the implementation of knowledge building is challenging as it requires high-level dynamics in classroom interactions. The teacher needs to shift their role and work with students to co-design and improvise their knowledge building processes as an inquiry unit unfolds (see Zhang et al., 2011 for a school case).

Related to this challenge, recent research in science education searches for ways to support teachers as they make the shift in the classroom to embrace higher-level uncertainty and dynamics and engage student agency (Ko & Krist, 2019; Manz & Suárez, 2018). Teachers need to work with students to monitor the evolving interests and ideas in their community, make sense of emergent problems, tensions and uncertainty, and be responsive in moment-moment actions (Cherbow & McNeill, in press; Harris, Phillips, & Penuel, 2012; Zhang et al., 2011). Complementing the research on the teacher’s role, the field needs to conduct deeper research on student-driven interactions through which they make agentic input to shaping the inquiry of their community as an evolving social activity system (Damsa, 2010). Educators adopting Knowledge Building and other inquiry-centered pedagogies often struggle to find a proper balance between teacher guidance and student self-directedness or between classroom structure and student agency (Biggers & Forbes, 2012; Gutierrez & Calabrese Barton, 2015; Manz & Suárez, 2018; Varelas et al., 2015). To deal with and rise above these tensions, deeper research is needed to investigate how student-driven, open-ended inquiry and collaboration may be structured and guided in a manner that engages student epistemic agency. Knowledge building communities adopting opportunistic collaboration provide a social context for us to investigate this challenging issue.

**1.2 Conceptual Framework: Agency for Expansive Knowledge Building through Reflective Structuration**

Based on our recent work (Tao & Zhang, 2018, 2021; Zhang et al., 2018), we propose that student-driven, expansive knowledge building can be co-organized by classroom members (teacher and students) through ongoing *reflective structuration*. We define reflective structuration as a reflective and emergent process by which members of a knowledge community co-configure shared inquiry structures over time to shape and reshape their collaborative efforts for knowledge building. This notion builds on the structuration theory (Giddens, 1984; Sewell, 1992) and other social theories on the temporal co-construction of social practices driven by human agency (e.g., Archer, 1982; Bourdieu, 1977; Goodwin, 2017; Sawyer, 2005). Below we elaborate on how reflective structuration serves as an emergent social mechanism to engage student agency for expansive knowledge building.

First, reflective structuration leverages co-constructed inquiry structures—which may build on pre-defined/existing classroom structures—to organize the joint inquiry of a classroom community. The co-constructed inquiry structures provide students with a shared framing of their unfolding inquiry practices (cf. Engle et al., 2012; Hutchison & Hammer, 2010), including (a) epistemic framing about what the community should investigate and pursue; (b) social configurations about who connects/collaborates with whom in what roles; (c) pragmatic framing of how the community should conduct its inquiry, collaboration and discourse; and (d) values and principles used to justify why the community should operate in specific ways. As our studies suggest (Tao & Zhang, 2018, 2021; Zhang et al., 2018), students can work with their teacher and with one another to co-construct such shared inquiry structures through an emergent process as their collaborative inquiry unfolds. For example, a Grade 5 classroom engaged in a yearlong inquiry on how human body systems work. Students worked with their teacher to frame/reframe what the community should investigate as their collective inquiry unfolded. As a shared inquiry structure, the community co-constructed and updated a chart of "big questions" to frame the unfolding directions and strands of inquiry. The visual organizer of the evolving "big questions" was posted on the classroom wall and in the online space, used by students to plan and monitor their inquiry work, form flexible groups, and reflect on emergent progress and needs. In response to the emergent questions and idea connections, students engaged in further reflective discussions to expand and reorganize the chart of "big questions" that guided deeper knowledge building (Tao & Zhang, 2021).

Therefore, co-constructing shared inquiry structures offers a social mechanism to guide students' participation in a way that engages their epistemic agency. Students enact epistemic agency through constructing shared structures of joint inquiry as it unfolds, shaping key aspects of their science practices such as what they need to figure out, how to conduct inquiry, and who should work with whom in what roles (Schwarz et al., 2017). The co-construction of inquiry structures takes place as a temporal emergent process. A classroom community may first appropriate and build on existing structures (e.g., curriculum guidelines) to formulate initial inquiry structures, which provide an open context for students to carry out exploratory inquiry and discourse. The structures mediate students' inquiry actions and interactions as students use the structures to plan, monitor, and adapt their work in a reflective manner. The ongoing interactions driven by students' diverse interests and ideas give rise to emergent changes in the community's inquiry, such as new/deeper questions, inquiry practices, tools, and social roles and connections. In response to such developments, members of the community engage in further reflective efforts to analyze their new context of inquiry and reposition what and how they should inquire in the next phase. New framing of inquiry directions and processes are formed in response to emergent needs and opportunities. Thus, the concept of reflective structuration has rich connections with the recent literature on student agency for co-constructing learning spaces, participatory pathways and relationships to sustain their science practices (Calabrese Barton & Tan, 2010; Damşa et al., 2019; Gutiérrez & Calabrese Barton, 2015). The above-presented conceptual account clarifies the social and temporal mechanism by which shared inquiry structures are constructed and adapted in a collaborative community as student knowledge building actions unfold.

Reflective structuration provides an analytical lens for investigating student agency to shape and reshape shared inquiry structures that mediate their unfolding participatory actions for knowledge building. We have conducted a set of studies in Grade 3-6 science classrooms to examine how students co-construct shared inquiry structures to frame/reframe their unfolding inquiry directions and processes (e.g., a chart of progressive inquiry cycles) as their inquiry work unfolds over an extended period of time (Tao & Zhang, 2018, 2021; Zhang et al., 2018). The data analysis documented the interactive teacher-student input to co-structuring shared goals (e.g. shared wondering areas and guiding questions) and inquiry processes. Such reflective efforts serve to enhance students' collaborative discourse and deep inquiry, leading to sophisticated scientific understandings. As an important aspect of epistemic agency, further research needs to investigate how students co-construct adaptive group structures in light of the evolving directions and needs of their community.

### 1.3 The Purpose of the Current Study

In a nutshell, efforts to implement authentic science practice require a clearer account of how expansive knowledge building processes can be organized in a manner that engages student epistemic agency. The study investigates reflective structuration as a mechanism for leveraging students' epistemic agency as they co-construct shared inquiry directions and group structures to support ever-deepening inquiry. Building on our prior studies (Tao & Zhang, 2018, 2021; Zhang et al., 2018), the current study aims to generate an elaborated account of how young students enact epistemic agency for co-constructing shared inquiry directions and opportunistic groups as their collaborative inquiry evolves. Specifically, this study was conducted in a Grade 5 science classroom that investigated human body systems over seven months using the Knowledge Building pedagogy with Knowledge Forum (Scardamalia & Bereiter, 2014). The teacher encouraged her students to take high-level responsibility for defining problems, planning and monitoring inquiry processes, generating theories and explanations, and continually identifying new/deeper questions for further inquiry. As shared inquiry structures, the knowledge building community co-constructed a set of "wondering areas" to frame the unfolding directions of inquiry and guide student collaboration in opportunistic groups. For example, a shared wondering area was formed around how people see, leading to the development of the eye inquiry group that operated and adapted over the next two months. In the above context, we investigated the following interrelated research questions.

RQ1: What agentic moves were enacted by students over time as they co-constructed shared wondering areas to deepen and expand their inquiry as a community?

RQ2: How did students form/reform inquiry groups to advance their shared knowledge in the evolving wondering areas?

RQ3: How did students work in co-constructed inquiry areas and groups to carry out collaborative knowledge building, with what support from their teacher?

## 2. Method

### 2.1 Classroom Context and Participants

This study was part of a multi-year design-based research (Collins et al., 2004) project to test classroom support for student-driven knowledge building in science. It was conducted in a fifth-grade classroom at a public elementary school, which was located in a suburban school district in the northeast US. The school was transitioning from its local science curriculum toward the Next Generation Science Standard (NGSS). During the transition, the teachers continued teaching the topics listed in their local science curriculum while incorporating science practices and teaching methods advocated by the NGSS. Their local science curriculum expected students to study human body systems and science processes in Grade 5.

The participants included 22 students and their teacher. The students, 11 boys and 11 girls around 10- to 11-year-old, came from diverse ethnic backgrounds. The teacher, Mrs. K, had 19 years of teaching experience and was in her third year of teaching science using the Knowledge Building pedagogy and Knowledge Forum (Scardamalia & Bereiter, 2014). The teacher worked with her students to study human body systems from September 2015 to April 2016. There were two science lessons every week, each lasting for 40 minutes. The inquiry process integrated face-to-face and online activities that evolved based on student needs. Students had access to a set of laptops used to conduct online research and collaborate with peers in the Knowledge Forum (see Figure 1).

< Insert Figure 1 here>

**2.2 Design and Implementation of Knowledge Building Processes**

Prior to the human body inquiry, Mrs. K, together with a group of Grade 5 teachers, participated in a one-day meeting organized by our research team. The teachers shared reflections on their science teaching practices in the past school year to support student knowledge building. They also discussed possible ways to enhance student collaboration and interaction for deeper inquiry supported by a set of principles (Scardamalia, 2002), taking into consideration their curriculum expectations, instructional time and resources available for science. Mrs. K then worked with a colleague from the same school to plan a set of kick-off activities to stimulate students' interest in and wonderment about the human body systems, expecting that the actual inquiry directions and processes would develop based on students' questions and ideas.

The kick-off event took place in mid-September. Students participated in a set of outdoor activities, each requiring them to perform a challenging task using various body parts (e.g., sitting in a chair to shoot a basketball in the hoop). A whole class reflective conversation was organized right after the outdoor activities for students to reflect on their personal experiences and generate inquiry questions. The teacher/students referred to this form of reflective conversation as a "metacognitive meeting," which, as differentiated from regular classroom discussions, focused on metacognitive issues of the inquiry work such as shared goal setting, process planning, and progress review. At the above metacognitive meeting, the classroom community built shared interests in understanding the amazing functions of the human body.

Students with interrelated interests and questions then worked together to formulate a shared wondering area as an inquiry direction, phrased using an overarching question (e.g., How do we see?). Thereby, the whole class created an initial list of collective wondering areas, and corresponding to the areas, an initial set of views (workspaces) was set up in Knowledge Forum as the online spaces for students' collaborative discourse. For example, a view called "Eyes" (Figure 1) was set up for the investigation of "How do we see?" Each student then self-identified a wondering area as his/her primary focus of inquiry, with members focusing on the same area forming a spontaneous inquiry group. Students were reminded that their work should not be limited by the area and group they had selected. They had the freedom to contribute and build on ideas across all the inquiry areas and move between groups at their own discretion.

Focusing on the identified wondering areas, students conducted personal and collaborative inquiry activities. These included individual and cooperative reading, model building and demonstrations, small group discussions, experiments, and whole-class discussions. Major ideas and findings generated through the classroom activities were contributed to Knowledge Forum for continual online discourse. As students made progress in the various areas of inquiry, whole class metacognitive meetings were held to share problems and knowledge advances, reflect on idea progress and connections, and identify new/deeper goals. Based on students' input, the community proposed deeper issues in the existing lines of inquiry and formulated new wondering areas, such as "How and why do you change when you grow?" New inquiry groups were formed while the existed groups adapted. New Knowledge Forum views were created for online discourse focused on the new wondering areas (see Figure 2).

< Insert Figure 2 here>

As an online space for ongoing metacognitive discourse, a special view was set up on Knowledge Forum called the "Best of Our Knowledge (BOOK)." Students posted reflection notes to highlight the key questions explored and new understandings gained in each area. These included ongoing reflections on their progress of inquiry and thinking and summary notes to synthesize what they had figured out (see Figure 3). Student reflections in this view were accessible to the whole class as well as the other three Grade 5 classes studying the same science unit.

< Insert Figure 3 here>

### 2.3 Data Collection and Analysis

We investigated the human body inquiry as a designed case of dynamic, expansive inquiry. This case was documented and analyzed using an interactional ethnography approach, which provides the logic of inquiry for investigating what learners construct in a temporal sequence of events as viewed through multiple levels of analysis (Green et al., 2007; Green & Bridges, 2018). Our data sources included classroom observations of each science lesson during the human body inquiry (35 lessons in total, from September 18, 2015 to April 21, 2016), video/audio recordings of major small-group work and whole-class discussions, records of online discourse (539 notes in all the Knowledge Forum views, with 60 notes in the view about eyes), students' personal notebooks and slides created to share their knowledge advances, and student and teacher interviews. At the end of the human body study, a researcher conducted a one-on-one interview (approximately 15 minutes each) with three students who made intensive contributions to the eye inquiry. The interview questions focused on how they managed and participated in the collaborative inquiry processes and what they had learned. We also conducted a semi-structured interview (35 minutes) with the teacher to understand her perspective on the inquiry process and her classroom roles. The interviews were fully transcribed for analysis.

We combined the above data sources to investigate the three research questions, each integrating multiple levels (units) of analysis that attended to the individual students, small groups, and the classroom community as a whole. Based on the observations of the classroom activities and online discourse during mid-September to mid-November, we identified the eye inquiry group as a "telling case" (Mitchell, 1984) of the opportunistic group because it demonstrated deepening processes of inquiry over an extended period with rich interactions documented. Four students—referred to as CH, ST, OL, and AS—formally identified eyes (How do we see?) as their primary inquiry focus. While the four students worked individually and collaboratively to investigate how people see, they interacted with the other peers both face-to-face and online. A total of 17 other students whose primary focuses were on other areas made occasional contributions to the inquiry of eyes in the classroom or on Knowledge Forum.

To investigate RQ1, we analyzed the classroom observations, video/audio recordings, and online discourse to trace how students' agentic moves contributed to the formulation, expansion, and adaptation of the collective wondering areas. Adopting practices of interactional ethnography research (Green et al., 2007; Green & Bridges, 2018), two researchers observed each science lesson and created a rich documentation of the classroom events, which were indexed and mapped based on time. The data organization provided contextual information about each major classroom event observed, time and topic of the inquiry activities, highlights of student and teacher participation, and sources of data recorded. For the analysis of RQ1, we particularly focused on classroom events in which the classroom members formulated new wondering areas or rephrased/reorganized the existing ones. Each event was analyzed based on students' interactions with one another and their teacher, with further analyses to trace backward and forward in search of connections between the current event and what happened before and after. Doing so allowed us to create an "intertextual web" (Green & Bridges, 2018) for making inferences about the processes leading to each structure change and the influence of such change on students' subsequent participation.

Deeper analyses were conducted for each of the identified classroom events, attending to students' interactive inputs to forming shared inquiry directions, reframing/expanding the scope of their inquiry, and monitoring inquiry progress and knowledge gaps/challenges over time. As noted above, as part of their reflective effort to monitor inquiry progress in the co-generated wondering areas, students posted reflection notes in the Best of Our Knowledge (BOOK) view to calibrate core inquiry questions and understandings achieved. Altogether there were 16 reflection notes posted. To understand student agency in shaping and directing their deep inquiry in each wondering area, we conducted content analysis (Chi, 1997) of each reflection note. Drawing on analysis procedures refined through our prior studies (Tao & Zhang, 2018; Zhang et al., 2007), the coding scheme examined the inquiry questions synthesized in each note and understandings (ideas) developed to address the inquiry questions. Questions were classified based on two dimensions: (a) explanation-seeking versus fact-seeking questions and (b) single-area versus cross-area questions. Explanation-seeking questions search for mechanisms, processes, and relationships (e.g., Why do we vomit? How do bones connect?) while fact-seeking questions ask for factual information relevant to a topic (e.g., What is in blood? Where is DNA?). A single-area question focuses on a specific body system or function (e.g., How do bones connect?) while a cross-area question ponders how two or more body systems work together (e.g., How does the brain get its energy?). Each reflection note was also coded based on student syntheses of their understandings related to their inquiry questions. Student understandings were coded using two four-point scales: (a) scientific level (1-pre-scientific, 2-hybrid mixing scientific information with intuitive understanding, 3-basically scientific, and 4-scientific) and (b) epistemic complexity (1-unelaborated facts, 2-elaborated facts, 3-unelaborated explanations, and 4-elaborated explanations). Two researchers coded all the reflection notes and obtained an inter-rater consistency of 90% (*Cohen's Kappa* = 0.82). Instances of disagreements were discussed to refine the coding process and generate the final results.

RQ2 and RQ3 (regarding co-constructed groups and student participation) were investigated based on data collected in the whole classroom complemented by a deeper analysis of the eye inquiry group as a telling case. For the analysis of the whole classroom, we traced the temporal process by which students co-formulated inquiry groups in response to the evolving goals/needs of their community. Specifically, we used the wondering areas formulated by the community as tracers to analyze students' evolving inquiry foci, with those co-working on the same area functioning as a flexible group. Through the temporal tracing and mapping of students' inquiry activities related to each area (group), we were able to identify the evolutionary changes of their inquiry themes, core contributing members, and major ideas generated in personal notebooks, small-group and whole-class meetings, and online discourse. We also reviewed our data records of major inquiry activities that involved the teacher's input to identify the roles she played to facilitate student collaboration and interaction. To further examine students' collaborative inquiry and interaction in the evolving wondering areas, we conducted a quantitative analysis of students' online discourse in the corresponding views (workspaces) based on the number of notes posted, contributors involved, the length of each note, and the temporal duration of the online discourse from the first to the last note contributed to each of the views. Social network analysis (Carolan, 2014) was applied to analyzing who had built on whose ideas in the online discourse.

The analysis of the eye inquiry group provided a more nuanced view of RQ2 and RQ3. The second author browsed all the observation notes, classroom recordings, and online discourse to identify major classroom events relevant to vision. These events were organized based on a chronological sequence to understand the history of the eye inquiry group (e.g., from its emergence to the unfolding inquiries till its dispersion). To trace the unfolding pathways (processes) of inquiry in this area, we conducted inquiry threads analysis (Zhang et al., 2007) to trace students' inquiry actions and discourse related to the various themes/problems that surfaced over time. Based on the classroom and online data, the second author identified the specific issues and problems investigated by the eye inquirers in various settings. Most of the issues and problems were clustered under three themes: #1 brain-eye connection, #2 image formation at the eye level, and #3 eye parts and functions mostly focusing on the role of pupils (#3a) and cones (#3b). We then traced student interactions and contributions related to the various themes across data sources. Events related to each theme were plotted as a chronological thread (line) of inquiry addressing a focal issue (see Results). Deeper analyses were conducted to generate a thick description (Greetz, 1973) of how each thread of inquiry was sustained and deepened through student interactions. To triangulate and validate the analyses, we examined the student and teacher interviews pertinent to how the eye inquirers pursued their inquiry and interacted with their peers and how the teacher worked with the dynamic classroom processes.

**3. Results**

We first report our analyses of the three research questions based on the human body inquiry as a whole dataset. Then, we address RQ2 and RQ3 at a deeper level by unpacking the case of the eye inquiry group.

### 3.1 RQ1: What agentic moves were enacted by students as they co-constructed shared wondering areas to deepen and expand their inquiry as a community?

Students played agentic roles in building on their personal interests and questions to co-formulate an initial set of collective wondering areas; reframing and expanding the wondering areas as their inquiry proceeded; and using the shared framing of inquiry directions to guide ongoing monitoring of progressive inquiry and collaboration across areas. These agentic moves allowed them to seek persistent idea improvement in the existing areas while generating new problems and goals that pushed beyond the boundary of their knowledge.

**(a) Co-formulating an initial set of collective wondering areas.** As noted in Method, the human body inquiry began with a set of outdoor activities planned by the teacher. Such activities served to elicit students' experience and reflection on the functions of the human body and further triggered their wonderments and questions. Students recorded their questions on Post-It notes. The whole class then gathered in the classroom to share their questions and interests. Students offered metacognitive input on how they should work together to research the human body. A student, MA, proposed that since they had questions about the various related topics, they should work in groups and put their questions together to create one big question in each area, so they could better find out the answers. The teacher supported this idea, saying: "*I'm going to give each group one piece of paper. You can huddle up your group, like … the brain group. I want each person in their group to share their question with the group and stick it to this place (paper) now. Do not judge each other's questions. Just listen to each other's* *questions*." Students with interrelated questions sat together to discuss their interests and formulate an overarching theme and question to guide their inquiry. The whole class then reconvened to share the overarching questions generated. As students shared, the teacher took note of the questions on a piece of chart paper and asked for further clarification as needed. A set of collective questions—referred to as "our wondering areas"—were generated (see Figure 4a). These include: (a) Bruises: How do bruises form? (b) Eyes: How do we see? (c) Digestion/throw-up: Why does the digestive system make us throw up? (d) Breathing: Why do we breathe air? (e) Brain: How does the brain control everything? (f) Bones and lefty/righty: How do bones work and why are there more righties than lefties? The teacher then posted the chart of wondering areas on the classroom wall to highlight what the community needed to investigate. Students posted their personal questions next to the related wondering areas to indicate their own interests of inquiry.

<Insert Figure 4 about here>

Inquiry groups emerged from the student-driven process to co-construct shared wondering areas. Students who were interested in each of the wondering areas started to work as a small group to carry out inquiry activities. At the same time, students with unique interests outside the existing areas were allowed to pursue their inquiry direction based on their choice. (For example, ME expressed an interest in understanding how hair grows, but no other student was interested in this topic at that time.) A Knowledge Forum view was set up for each wondering area as the collaborative online space (see Figure 1 as an example). Through the above processes to co-construct the initial wondering areas, which were reified using the classroom chart and Knowledge Forum views, the community formed an initial organizational structure to coordinate members' knowledge building contributions and interactions.

**(b) Reframing and expanding the wondering areas based on emergent progress and needs.** Students worked in and across the identified areas to conduct inquiry using classroom-based and online resources. As their inquiry generated new understandings of the human body functions, students continually raised deeper questions. Students contributed ideas and questions in Knowledge Forum for online discourse. In response to the emergent progress and needs of knowledge, the classroom members engaged in further reflective conversations to revisit and reframe what they should investigate for deeper understanding. Figure 5 shows the temporal changes of the community's framing of collective inquiry directions. Some of the existing wondering areas were reframed and elaborated based on the updated understandings while a set of new wondering areas were added to expand the community's inquiry. For example, students' inquiry of how bruises are formed led to the understanding that bruises look purple because of the blood leaking under the skin. Based on this new understanding, they decided to rephase their wondering area as about bruises and blood. Extensive inquiry and discourse took place focusing on what is in blood, how blood is made, and how blood travels. Similarly, the students who worked on the wondering area of "How does digestive system make us throw up?" revisited their overarching question through a small group meeting with the teacher held on October 20. The group members shared their detailed understandings of the process of digestion. The teacher praised them for their rich understandings and facilitated further reflection by asking: "*So, do you think that is related to your question: why do people throw up?"* The students recognized that their work was far beyond their initial question. They discussed options to rename their wondering area, and eventually decided to describe it as "How does the digestive system work?"

<Insert Figure 5 about here>

In addition to reframing the existing areas based on inquiry progress, students also formulated several new directions of inquiry in November and January based on new questions and interests (see Figures 4b and 5). For example, in the inquiry about right- versus left-handed, students first focused on understanding muscles and bones in the hands. The information they gained from books and online sources made them realize that handedness has to do with genetics, triggering their curiosity about genes and DNA. The members of this group shared their new interests with the whole class and proposed that a new wondering area be added to their collective chart. This suggestion received support from the teacher, who asked for students' input to formulate an overarching question. Based on students' input, a new wondering area was added: "What is DNA?" Two students working on lefty/righty decided to pursue this new inquiry about genetics. Two other students from the brain group also volunteered to work on this topic, building their prior inquiry on how children's talents are impacted by their parents. Later, the inquiry of genetics further gave rise to a set of new questions, such as "How and why do you change when you grow?" A new area was set up focusing on human growth in late November (see Figures 4b and 5), and a new view was created in Knowledge Forum to support students' discourse in this area.

**(c) Reflective monitoring and navigation of inquiry across areas.** On an ongoing basis, students used the co-redefined wondering areas as a reference to position their personal participation and reflect on shared progress in understanding the core issues about the human body. They created "rise-above" artifacts to document their emergent progress and problems, which were shared between different inquiry areas and groups. As noted in Method, students shared their reflection in the Knowledge Forum view called "Best of Our Knowledge (BOOK)," which was visually organized based on the wondering areas (see Figure 3). Students working on each area posted reflection notes to highlight the problems they had investigated and new understandings developed through their inquiry as a group. These included periodic reflections on their progress (journey) of inquiry and summary notes posted toward the end of their inquiry. Altogether there were 16 reflection notes posted. Content analysis revealed students' in-depth reflection documented in these notes to calibrate their inquiry questions and understandings (see Table 2). The reflection notes included a total of 30 questions. Among them, 23 were explanation-seeking questions wondering about mechanisms, processes and relationships; and seven questions searched for important facts (e.g., What is in blood?). Half of the inquiry questions focused on a specific body system or function while the other half investigated how two or more body systems work together. For example, one of the inquiry questions focused on how the brain gets its energy, which looked at the connection between the brain and digestion and circulation. In each of the reflection notes (except one with missing information), students further synthesized their new understandings developed to address their inquiry questions. Their understandings were mostly (13 out 15) rated as "scientific" on the four-point scale (from 1-pre-scientific to 4-scientific), presenting detailed accounts of scientific facts ($n$ = 6) and elaborated explanations ($n$ = 7). An example summary note is shown in Figure 3, which offers an elaborated explanation of how people see.

<Insert Table 1 here>

The teacher encouraged students to read the notes posted in the BOOK view so they could learn from the knowledge advances of the different areas and make connections. As a rise-above event, a metacognitive meeting was further held in March for the whole class to reflect on knowledge connections between the different areas of inquiry. Students sat in a circle to contribute to this conversation, with a piece of chart paper placed in the middle. As they took turns to identify how the different body systems (e.g., respiration and digestion) worked with one another to support their functions, they took notes of cross-system connections on the chart paper. This resulted in the creation of a visual map showing how different body systems work together, connecting what students had learned in each of the wondering areas (see Park & Zhang, 2019 for a detailed analysis).

### 3.2 RQ2: How did students form/reform opportunistic groups to build knowledge in the evolving wondering areas?

For the analysis of RQ2 and RQ3, we first present a bird's-eye view of the inquiry groups formed over time in the whole community. More detailed analyses are presented in the next section focusing on the eye inquiry group.

The analysis of RQ2 traced the temporal process by which students co-formulated flexible groups in response to the evolving inquiry directions and needs of their community. As noted above, the collective chart of wondering areas was used to highlight the evolving goals of the knowledge building community. With a sense of the collective goals, each student chose one (or more) wondering area as his/her primary focus over a period of time. Those focusing on the same area formed an inquiry group. Their personal foci and group connections shifted as the community's wondering areas were further elaborated and restructured and their personal interests and connections evolved.  To investigate the emergence and adaption of student groups, we traced the primary inquiry focus identified by each student at the various points of the human body inquiry. Table 2 shows each student's path of inquiry, which crossed with the paths of their peers in temporally evolving areas.

<Insert Table 2 about here>

For example, four students (ST, OL, AS, CH) formed a group to study eyes and how people see. An in-depth analysis of this group is presented in the second half of the Results section. As another example, JE, and JU collaborated in late September to investigate lefty/righty. They were joined by BR in October as their inquiry included issues of bones and joints. As the inquiry of lefty/righty further gave emergence to the topic of gene/DNA in early November, JE and JU started to collaborate on this new topic together with RU and SE, who were formerly members of the large brain group. The brain group formed in late September went through major restructuring in November and then January. Besides the shift of RU and SE to the inquiry of gene/DNA, KE and IS, together with EM formerly working on breathing, decided to investigate hair (and lice). As noted in the previous section, the inquiry about hair was a minor topic initiated by ME in September. Then around early November, an instance of head lice occurred in the school building, making many students interested in understanding more about hair and lice. KE, IS and EM volunteered to collaborate in the inquiry of hair (and lice), which was later expanded to include how the skin works. ME did not join this new group as her inquiry interest had shifted to digestion.

As the analysis suggests, the process to co-construct inquiry groups involved both intentionality and serendipity. Students continually monitored the evolving ideas and directions of their community and (re)positioned their personal and collaborative contributions accordingly while making improvisational responses to unexpected events and challenges to create opportunities for knowledge building.

### 3.3 RQ3: How did students work in the co-constructed inquiry areas and groups to carry out collaborative knowledge building, with what support from their teacher?

Building on the analysis of RQ1 and RQ2, we further examined how students worked in the evolving areas and groups to carry out collaborative knowledge building with teacher support. While each student focused on one (or more) wondering area and adjusted his/her focus over time, students were encouraged to take collective responsibility for advancing their understandings across all the areas. Students shared and built on one another's ideas in continual knowledge building discourse, including face-to-face talks and online discourse.

For the online discourse, a total of 15 Knowledge Form views were created for the various wondering areas. Table 3 reports measures of students' participation in the online discourse in each view (excluding the teacher's notes). In 11 (out of 15) views, students had active continual discourse, each with more than 20 notes contributed over multiple months for continual idea build-on and revisiting. The four less active views (with less than 20 notes each) focused on specialized topics that emerged relatively late in the inquiry. Comparing the authorships of notes in each view and students' group affiliation recorded in Table 2, we can see that almost every view (except the topic area about nose) involved contributions from the broader classroom members who focused on other areas. For example, while three students collaborated as a group to investigate bones (see Table 2), the discourse in the Bones view involved contributions from 12 students.

<Insert Table 3 here>

Students read their peers' notes and occasionally built on their notes to share questions, ideas or new information. As a result, they not only built connections with peers in their focal area(s) but also interacted with peers across the different views (online spaces). Figure 6 shows the social ties formed among the students through build-on responses, including a sociogram for the period of October to December and another for the whole inquiry that continued till mid-

April. As an example of the small groups formed, the sociograms include special marks for the students who focused on the eye inquiry from October to December. The extensive social ties suggest that the whole community operated as a coherently connected network as opposed to isolated subnetworks formed based on different small groups. Students, such as the eye inquirers indicated in Figure 6, not only interacted with their small group members but also with the broader members of their community for collaborative knowledge building.  A more detailed analysis of their online and face-to-face interactions is presented under 3.4.3.

<Insert Figure 6 about here>

Based on the classroom observations, online discourse and teacher interview, our analysis further looked at the teacher's dynamic role to support student-driven inquiry and collaboration. In the final interview, Mrs. K highlighted a key role she played in the classroom and online as an attentive listener/observer and responsive co-designer working alongside her students. She worked actively to understand students' interactive questions and ideas, envision opportunities for deeper inquiry, and offer the needed support to move the collective discourse forward while attending to the needs and progress of individuals and small groups. She said in the interview:

> "I read the notes in KF (Knowledge Forum)…just get an idea of what students' questions are, their understandings, their theories. And also try to…see around the classroom...(like) what they were doing…Then push myself to think I should I do with them next… I felt every class I have targeted, like 2 or 3 groups who I want to get to. And then otherwise I just kind of looking at what's really going on in the classroom at the time… meeting with small group students during class and then taking notes, even with individual students. So when I took notes, and I could reflect on that, and see, you know… it seems ready to have a

metacognitive meeting with the brain group because several students have questions, theories."

In the classroom and online space, Mrs. K observed and took notes of students' evolving interests, questions, and inquiry progress as individuals and groups. In the online discourse, she posted a total of 19 notes in the various views. Among those, 17 notes built on students' posts to ask questions, prompting students to clarify information or generate detailed explanations. In the classroom, she walked around to capture and make sense of students' inquiry works and ideas and sometimes joined one or a few students for a short conversation about their works. In such meetings, she often expressed excitement about their ideas and inquiry works and asked metacognitive questions to facilitate their reflection, such as: What are you trying to figure out? What have you learned so far? So, what do you wonder next? She further facilitated emergent collaboration and knowledge sharing in whole classroom settings, building on what she had observed in students' personal and collaborative works. Specifically, she often served as an advocate to select and highlight students' high-potential questions and ideas to the whole class, built on the questions and ideas to suggest directions for deeper/new inquiries, and created bridges between different areas (groups) of inquiry to expand student connection and collaboration. As part of the whole-class metacognitive meetings, the teacher occasionally shared epistemic reflections on how to research and collaborate like a science team and modeled specific inquiry practices and norms to students. She used students' questions and wondering to open a conversation, encouraged diverse ideas and peer build-on, and synthesized take-away points from each whole class discussion. As a student recalled in the end-of-year interview:"She (Mrs. K) always says when you learn new information, you don't want to keep it all to yourself. You want to share with other people."

### 3.4 A telling case: A temporal view into the eye inquiry group

For a deeper investigation of RQ2 and RQ3, we looked into the case of the eye inquiry group. The analysis generated a thick description of how the eye inquirers self-organized and interacted as a group to advance their inquiry of human vision in connection with the other areas/groups of inquiry in their community.

#### *3.4.1 How was the eye inquiry group formed?*

The kick-off activities triggered student interests in how the brain controls various body parts. After the kick-off, on September 22, students were asked to browse a collection of science books and take note of new information and questions. ST and CH, who were personal friends, worked together to read a book on brain control, which had an illustration of the brain regions and their functions. Noticing that the vision center was in the back of the brain, they were curious how it could possibly connect to the eyes.

> ST: So…that blue part is for thinking, speech is for the dark blue part, hearing is for that, tasting and touching for the dark green part, body movement is for light green.
>
> CH: So brain is actually of different colors?
>
> ST: No, it's all one color. But they use different colors just to make it…
>
> CH: …to see different sections of brain, body.
>
> ST: So one thing I don't get it though is your eyes are right here, and your vision is in the back of your brain. This is a very long (distance)…
>
> CH: This is confusing.

ST and CH continued to read the book but did not find a satisfactory answer to their question. In the following science class on September 25, students were given more time for personal research and question generation. ST and CH revisited the above question, noting that "*the back of your brain is connected all the way through to your eyes… We just don't know what that is."* Another student, OL, overheard their talk about eyes and approached them to share what she was reading in a book, showing how light is received on the back of the eyeball and images are formed. ST and CH asked OL to join them studying eyes. ST then had an accidental observation and came up with a question about pupils.

> ST (speaks to CH): Look at me. Why…why can I see myself in it (CH's eyes)? Why is it glossy?
>
> CH: You know the clear substance, like jello, it goes around it. So it makes it shiny.
>
> ST (turns to several other girls sitting near her): Have you ever wondered why you can see yourself in JU's eyes? Cause this glossy jelly…We wonder why we have pupils? CH and I are trying to figure that out.
>
> CH: Wait...guys, what parts in your eye make you actually see? Oh yeah, we should write that down.
>
> …
>
> CH: ST, to your question, I sort of have an answer to the first question: Why can we see our reflections in other people's eyes? Ours eye are kinda just like a glass mirror. Because you know, the clear substance around the eyes. It's kinda like a mirror.
>
> OL: It's right here (points to a book page). Each eye works like a camera.

In the above excerpt, the triad discussed a serendipitous observation of their eyes, which served as a context for their wonderment about pupils and the use of a metaphor (e.g., "Each eye works like a camera"). As the conversation continued, the students wrote down questions in their notebooks, which were later investigated in their inquiry (see the threads of inquiry below). Near the end of the class, they were still wondering about how the back of the brain possibly controls eyes across a distance, further problematizing the mechanism of brain control in general.

> CH: I don't know whether it would be weird…but why do we have brains? Why don't we just have different parts of brain that controls different parts of the body in that specific spot? So like the part that controls arms, why isn't it in the arms? It is easier.
>
> OL: Yeah, why isn't our eyeball on the back of our head (with her hand touching the back of her head)? …

On September 29, during the whole class metacognitive meeting to form shared wondering areas, ST, CH, OL, and another student, AS indicated their interests in studying eyes. They came together to share their personal questions and create a guiding question. Building on their initial explorations and conversations, the four students shared a set of questions, including: Why do our eyes work like a camera? (OL) How is vision area in the back of the brain connected with eyes? What parts in your eye make you actually see? (CH) Why is your eyesight upside down? (CH, AS) Reflecting on these specific questions, OL proposed a general question: "I have a big question: 'How do we see, if our eyes are (seeing things) upside down? The teacher dropped by this small group and suggested that they keep their question more general while they could include the more specific questions during their research. The four students agreed and decided to frame their area of inquiry as “How do we see?” The teacher later added their question as one of the collective wondering areas for the whole community (see Figure 4a). ST, CH, OL, and AS formed the eye inquiry group based on their shared interests.

#### *3.4.2 How did the group members interact with one another for progressively deeper inquiry?*

With the overarching goal to understand how people see, the students investigated their initial questions while continually uncovering new/deeper problems, which became the foci of several interconnected threads of inquiry that expanded over time. Our analysis identified the core questions they raised and investigated, addressing issues related to brain-eye connection, image formation in the eye, eye parts and function including pupils and cones, as well as blindness and tears that were studied as minor sub-topics. Figure 7 shows our tracing of students' major inquiry activities and progress to investigate brain-eye connection, image formation in the eye, and specific eye parts and functions (pupils and cones). Below we zoom in each thread of inquiry to understand how students' interactive input gave rise to shared inquiry goals and progress over time, which involved both intentional pursuits and serendipity of encounters.

<Insert Figure 7 about here>

***Inquiry thread #1: How does the back of your brain control your vision?*** As noted above, searching for possible brain-eye connection happened to be the initial interest of the students who later formed the eye group. After the eye group was formed on September 29, ST, CH, OL and AS conducted individual and collaborative work to understand the brain-eye connection, using books, magazines, websites, and models of the human body. Their initial search focused on the physical connections between the eyes and the brain. Later they developed new understandings of the functional connection between the brain and eyes based on image perception and visual information processing. They differentiated the functions of the eyes and brain in the process of seeing (vision), as the former helps form raw images while the latter helps a person be aware of the images. A set of notes were posted online recognizing that photoreceptors in the eyes sense light and send the information to the vision center in the brain via optic nerves. With the understanding of the functional connection, students further revisited their questions and ideas about the physical connection. For example, on October 27, when a model of a human skeleton was brought to the classroom, ST, CH, OL, and a few other students observed the little holes in the back of the eye sockets. CH commented: “I think that the optic nerve goes from your eye through that hole into your brain.” As a spontaneous experiment, CH tested watching an object with one eye versus both eyes. She saw the same thing from slightly different angles and inferred that the messages from the two eyes are possibly merged somewhere in the brain. In a science class on November 6, the students found a diagram in a book showing the neural pathways (e.g., optic tract). The information confirmed CH’s thoughts and further clarified how messages from the two eyes are transmitted and merged.

***Inquiry thread #2: Why does your eye work like a camera?*** This question was generated by OL based on a book she read on September 25. And she shared this question with ST and CH. Later ST and CH developed a deeper understanding of how eyes work like a camera. They read about the cornea that focuses light on the retina and about the fact that images formed in the eyes are upside down. On October 2, ST was curious why some people need to wear glasses. OL shared a book that had a related section. From that book, ST and CH learned that the shape of the cornea and eyeball influences visual acuity and that eyeglasses redirect light to focus on the retina. They also read about nearsightedness. It came to ST’s attention that nearsighted eyes resemble a camera zooming in to particular objects. And CH commented that this information was helpful for answering OL’s question on why eyes work like a camera. Near the end of the lesson, the eyes inquirers had a brief discussion on how glasses work to help a person whose cornea is not working properly. They built on each other's ideas and figured out that lens, cornea and eyeglasses are equivalent in function. In a subsequent class on October 13, CH, ST and OL watched a video about vision problems. Through an iterative process of watching a segment, discussing what they heard and saw, and taking notes of new information and questions, the students expanded their knowledge about farsightedness, concave and convex lens, and laser surgery. Later, ST and CH learned that an astigmatic person had a blurry vision at all distances. AS read and took notes about the similarities and differences between eyes and camera and posted a note online to answer OL's question about how eyes work like a camera.

***Inquiry thread #3a: Why do people have pupils?*** As noted above, this question emerged in a conversation between ST and CH on September 25 as part of their discussion about how the brain controls vision. A student, KE, who focused on how the brain works, overheard the question of "Why do people have pupils?" He asked: "What are pupils?" ST replied that pupils are "the little black dots in your eye" and that they needed to figure out the function of pupils. KE brought over a book that had a section about the brain and eyes noting pupils' function of controlling the amount of light going into eyes. But ST and CH were busy reading their own book and rejected KE's offer. In the following class on October 2, CH was excited to see two illustrations in a magazine showing different pupil sizes, indicating that pupils get bigger in the dark and smaller in the day. CH discussed this information with ST and reflected on their personal experience while taking notes in their notebooks:

ST: …I think eyes get bigger in the night to see more cause it's dark. (writes in notebook)

CH: And then… in the daylight, your pupil gets smaller. (ST said "gets smaller" simultaneously).

ST: Ahh, I know why. Because you can see everything. [CH: you can see well, so…] Yah, you can see everything so they don't have to do much work.

CH: Oh, I just came up with another question that has to do with this.

(ST walks away to tell a peer about what she learned about pupil size in daytime and nighttime, and then walks back.)

CH: You have very tiny pupils. Wait. Close your eyes for ten seconds [ST closes her eyes]… Open them [ST opens her eyes]. WOW. Ohhhhhh (deep inhale)

ST: What? What?

CH: They (pupils) just moved a little bit! (high pitch, excited) They just got bigger and then they went back smaller.

(Several students were attracted over.)

RU (a student working on brain): What do you mean?

CH (closes her eyes, counts to 10, and opens her eyes) RU, now look at…the pupils.

RU: Ahhh…

ST: That actually does work! So…we proved it. I have to get that down…

CH: That was so cool. We did an experiment!

Later, ST and CH shared this finding with AS and OL. On Knowledge Forum, RU wrote a note about pupils letting light in to help people see, pointing out that "the pupils get bigger when it's dark and smaller when it's bright."

***Inquiry thread #3b: What are red cones and how do they help you see?*** As mentioned above, CH and ST read about the different eye parts on September 25. CH asked a question: "What parts in your eye make you actually see?" Later, the members of the eye group learned that eyes function like a camera and that the image formed in the eye is upside down. But they did not know where the image is formed in the eye. In the subsequent science class, ST and CH read a book that had dense sentences mentioning "retina", "light-sensitive cells", "rods and cones" and "optic nerves." They commented that this information helped them understand the eye-brain connection better, but they did not pay close attention to any particular eye part noted in this book (e.g., rods and cones). In early October, when studying visual acuity, ST and CH read a magazine about eyes and encountered information about the retina's location and its role of being where the light is focused. A greenish picture on the page piqued CH's interest. She and ST read the text: "*A person whose red cones are either lacking or not working properly sees an abnormally strong green picture. Color blindness affects only about eight percent of all people, mostly males, and it is usually inherited…*" They examined the greenish picture again and still felt confused. CH asked: "What are red cones?" ST suggested that they record the question in their notebooks. She wrote down the question as "What are red cones and how do they help you see?" The dyad later shared their question with OL and AS.

On October 16, ST and OL found more detailed information about rods and cones on a webpage. They discussed the relevant information and took notes in their notebooks.

> OL: Rods == intensity (of light). My question was, at night do we use rods more than we do in the daytimes?

> ST: Probably yeah… rods allow you (to see) in low light. But cones, they help us see colors… They are like photoreceptors. Two kinds of photoreceptors: rods and cones. And they are in the retina.

ST tried to search for more information about red cones on the website but could not find anything helpful. She came up with a personal thought: "If red cones make us see green, then there are probably differently colored cones, like blue cones that can see orange. Because I thought red and green are opposite colors, same with blue and orange…" Her expression showed her conjecture about the role of different cones with a misinterpretation that red cones (instead of the misfunction of red cones) make people see green. Using the limited resource about color vision available and accessible to their age level, students in the eye group improved their understanding of cones, resolving the above misinterpretation. ST and CH wrote an online post to share their knowledge: *"…our (eyes) have different little cones that see different colors. And maybe red cones see the color red and maybe there are other small cones like blue cones."* AS posted a related note to offer additional thoughts: "*My theory is light receptors within the eye transmit messages to the brain, which produces the familiar sensations of color. Newton observed that color is not in [the] objects. Rather, the surface of an object [reflects] some colors and absorbs all the others, we perceive only the reflected*."

In late October, the four members of the eye group reflected on their progress of inquiry and co-authored a note to summarize their new understandings, which highlighted a set of key ideas developed in the above-analyzed inquiries (see the note shown in Figure 1). In early November, one of the eye group members, AS, shifted his focus of inquiry toward understanding how the brain works. He joined several other students who had been investigating the brain.

On November 13, the whole class had a metacognitive meeting focused on eyes and how people see. CH, OL, and ST interacted with the whole class to share their understandings, respond to peers' questions, and develop integrated knowledge about how the different body parts work together (see the detailed analysis of this meeting in the following section). Based on their inquiry on the brain-eye connection, ST, CH, and OL decided to learn more about the brain itself in January, with a special interest in what happens when people dream. OL was also interested in brain-blood connection, about which AS formerly asked a question. AS, a former member of the eye group, worked with other peers on how the brain works in November and December, and then shifted to understanding how the different senses work (ears/nose), building on his knowledge developed about the brain and vision.

As a brief highlight, the above analyses documented the collaborative interactions among the eye inquirers. The group members developed unfolding pathways of inquiry in the evolving context of the community's inquiry work, with new and deeper problems continually emerging as the inquiry progressed. As CH reflected in the interview: *"When I found answer to my question, I would always have another question in mind."* Students shared questions and wonderments with one another, and built on what they had known to generate tentative answers and explanations, which were examined and refined through further inquiry involving readings and observations. Over time, the eye inquirers revisited their driving questions, reflected on personal and group progress, and decided what issues they should further investigate using what resources.

### *3.4.3 How did the eye inquirers interact with the members of the whole classroom*

Additionally, our analyses examined the expanded interactions between the eye inquirers and other members of the classroom. These included (a) informal exchanges during day-to-day inquiry activities, (b) online discourse and sharing across groups/areas, and (c) periodic whole class meetings for connection building across areas.

***Spontaneous exchanges of ideas and inquiry practices in the classroom***: During their day-to-day inquiry activities in the classroom, the eye inquirers occasionally visited the other inquiry groups or students to share new ideas. Students working on other inquiry areas also joined in the eyes inquirers sometimes to discuss interconnected issues. Besides exchanges of specific ideas, questions and resources, students also shared reflections on how to approach their collaboration and inquiry as an integral part of their classroom discourse. The eyes inquirers actively contributed to such conversations. The teacher sometimes captured and used their works as examples to showcase group collaboration and reading strategies (e.g., note-taking strategy using a "what and so-what" format). For instance, on September 29, in an improvised conversation, the teacher asked students to share thoughts on why they needed to collaborate with peers. Two eye inquirers (OL and CH) and several other students contributed to this conversation.

OL: They might have different information than you and you can learn about.

Teacher (T): So you could learn from people in your group because they might have info you don't have. CH.

CH: In a group, it's much easier, because instead of all over the place, it's quicker to find…what you're trying to find.

T: Give me a thumb up if you agree with CH. Can you hear her over there? She just said something really smart…

MA: We could all know things. We could put the things together...

T: Wow. I love MA's idea… All 22 of you need to understand the human body…I do not think you can teach all to yourself. I think you're going to need to learn from each other.

Reflective conversations as such contributed to the formation of shared norms and expectations in the classroom. Social norms developed through such conversations (e.g., mutual listening and build-on) were referred to and revisited in the subsequent science lessons to guide student participation.

***Online discourse across groups and areas***: Besides the spontaneous (informal) classroom sharing and conversation, community-wide exchanges were further supported by the online discourse and whole-class meetings featuring the progress of each group. In the Knowledge Forum view about eyes, 60 notes were contributed by 16 students and the teacher. Among the 60 notes, the teacher posted four, which offered suggestions and prompts on how to title a note, write notes with personal understandings, and plan for further inquiry. The members of the eye group co-wrote two summary notes (which were also shared in the BOOK view). The rest 54 notes were posted as interactive discussions. While 13 (24%) of the notes were generated by the four members of the eye group, 41 (76%) were created by other students (12 students) whose primary focuses were on the brain, digestion, breathing/lungs, and left-handedness, and so forth.

Beyond the Eyes view, the eye inquirers also interacted with their classmates in the other views about the various body systems through reading and building on notes. As the afore-presented social network analysis (see Figure 6) shows, extensive social ties were formed between the eye inquirers and their broader peers. One of the eye inquirers, ST, reflected on how such extended interactions created opportunities for knowledge building: "*When I was talking to JE and JU (who were exploring gene/DNA), they said your iris (color) is part of DNA. So it connects!… I got to learn not just about eyes. I got to learn about genes, DNA and brain too while studying eyes.*"

***Whole-class meeting featuring the eye inquiry***: On November 11, ST, CH and OL proposed to share their knowledge with the whole class. The teacher met with them to understand and support their planning. Students reflected on the major concepts and ideas they would like to share and discussed how they might use diagrams to share knowledge. The teacher prompted the students to think about what questions their classmates might have and how they would respond.

T (Teacher): Are you guys prepared for the questions that are going to come up?... Did you see the question on your (KF) view?

…

ST: We saw BR's.

T: About blindness? (ST/CH: yeah) Did you answer that on KF (Knowledge Forum) already?

ST: No.

T: You can answer it in our metacognitive meeting. But do you have an answer? (ST/CH: um-hm) So what's your understanding about blindness?

ST: Sometimes when kids are born, their eyes are shaped in different way, shaped in more oval. And it kind of like… it makes their vision little different.

CH: And I think objects appear blurry…

T: …you could take today to find a little more about blindness, so you can answer those questions (ST/CH: yeah)… And it's also OK at the metacognitive meeting to say "I don't know." You don't have to feel like you have to answer everyone's questions, because maybe putting our knowledge together, other people could help answer and join. Someone could research along with you.

On November 13, the whole class had a metacognitive meeting focused on eyes and how people see. The teacher opened the meeting and reminded students to all take notes in their notebooks: *"Put date in your notebook. At the end you will summarize what was talked about and what you learned. This means you need to pay attention during the meeting."* Following the eye group's plan, OL first shared knowledge about the different parts supported by the information recorded in her notebook. The teacher encouraged her to talk with (not simply read) her notes: *"I think sometimes if you just read what you have in your notebook, it might not make so much sense to us… We don't know a lot about the eye as you do."* As OL, ST, and CH continue to present, the classroom talk quickly turned more conversational.

OL: Cornea is transparent cushion of the eye, the outer cover of the eye.

T (teacher): You start to say it's the complete outside covering? (CH/ST: Yeah)

ST: It looks glossy in your eye.

T: Oh, it looks glossy when you look up at the light?

ST: Yeah. That's why if I look at CH's eye, I can see myself.

OL: The iris is the muscular part of the eye that controls size of your pupil.

CH: So when your pupil opens, gets bigger and smaller, that muscle helps make it bigger or smaller.

ST: In the dark, if I turn all the lights off and close all the blinds, then it's gonna be dark. My eyes…

CH: The pupil will get bigger…

ST: Because it wants to see everything.

CH: Yeah, it's trying to get as much light as possible inside.

ST: Now because there's a lot of light, your pupil is getting smaller because it can see everything clearly.

CH: It doesn't have to (get) as much light in.

In the above excerpt, OL, ST, and CH shared their knowledge developed through the various lines of inquiry in their group, such as about how eyes work like a camera and how pupils work. Then the teacher saw BR raising his hand, the student who she knew had asked a question about blindness in Knowledge Forum.

T (teacher): OK. You've given a lot of info. I see BR has a hand up. Why don't you let some of the people in the class interact with what you're saying?

BR: When you blink, does your pupil get anything?

CH: I don't think it makes a difference (ST: cause it's just a second). Also about that, if you keep your eyes closed for maybe 10 seconds, actually it's an experiment we did at the beginning, your pupils will get bigger and then go back to regular size.

Interestingly, BR did not ask the question about blindness that the eye group had prepared for but, instead, raised a somewhat trivial issue about blinking. CH improvised and built on BR's question to share what they learned from their exciting experiment about pupil sizes (see inquiry thread #3a). Similar patterns of conversation occurred in the subsequent episode in which the eye inquirers devised informative responses to their peers' questions and further improvised to share deep knowledge.

> MA: Why…when you start to get sleepy, your eyes just automatically close.
>
> CH: Well, I guess that means you're tired and your brain is telling your eyes that you're getting tired. In the back of your eye there's optic nerve. When light comes in, the optic nerve…can sense what kind of object or person you're looking at, and sends messages to your brain. And your brain sends messages all the way back to your optic nerve. And so I guess your brain will tell optic nerves that you're getting tired.
>
> ST: And you have two eyes, so you have two optic nerves. We predict that they connect and go to the back of your brain.
>
> CH: The back of the brain controls your vision.

The eye inquirers continued to respond to peer questions, using their knowledge to address issues related to eye adaption to light change, retina, rods and cones, and color blindness. A few students raised questions that the eye group had not investigated (e.g., brain damage and illusion, eye color, and genetics). The teacher encouraged students working on different topics to put their knowledge together to address the questions (e.g., why people have illusions). The teacher said: *"Anybody in the brain group wants to add onto this, because I think they are making a good connection between eye and brain."*

> JO (a student focused on brain): The reason (of concussion) is when you hit the back of your head, where your visual cortex is…
>
> AN (a student focused on brain): I wanna add onto JO. Concussion, like what you said, is when your brain shakes. Sometimes you can get a bad really bad concussion, you get amnesia. [Teacher: what's that?] It's when you forget to do something…I studied this… If you get concussion and amnesia, that might be one of your neural pathways break. That's what I think.

Rich discussions followed to explain neural pathways and other issues (e.g., color blindness). AS, a member of the eye group from September to October, contributed to explaining how partial color blindness may be caused by problems of different cones. The teacher was impressed by how students built on one another to build and share knowledge, saying: *"You guys did a really good job in explaining all of different parts and their functions, how they work together with the brain to get us vision."*

CH, ST and, OL continued their inquiry about vision after the above whole class meeting. In the Eyes view, students posted new notes about contact lens, eye muscles that played a part in visual acuity, and brain processing of visual information. OL was amazed by the fact that *"About three quarters of all information in the brain comes in through the eyes alone."* (a note dated December 8) The three students further reflected on their knowledge and co-authored an updated, more detailed summary note in the BOOK view in mid-December, supplemented with a few slides. The students wrote:

> "We have figured out: that the eye has different parts to it that work together to help us see. Some of those parts are the iris, the pupil, the lens, the retina, the cornea, and the optic nerve.  The iris and the pupil work together when light shines through the lens, and on the iris, so that it controls how big and small your pupil gets. The retina is the part of your eye that has rods and cones. Rod and cones and different photoreceptors..."

## 4. Discussion

This research set out to investigate how dynamic, expansive knowledge building practices can be organized in the classroom in a way that engages student epistemic agency. Guided by the conceptual framework of reflective structuration, our analysis examined students' interactive and agentic moves to co-construct shared inquiry structures as their knowledge building work proceeded. The results enriched the findings of our prior studies (Tao & Zhang, 2018, 2021; Zhang et al., 2018) in understanding student epistemic agency for co-constructing shared inquiry directions and group structures to guide their ongoing participation, which led to progressively deepening inquiry with dynamic idea exchanges and build-on among students. We discuss the following findings in light of the related literature.

### 4.1 Students Enact Epistemic Agency through Co-Constructing Shared Inquiry Directions and Group Structures Over Time

The literature has recognized epistemic agency as a hallmark of science practices and identified various dimensions of epistemic agency, focusing on epistemic moves to shape/reshape the participatory processes and structures through which knowledge building work takes place (Damsa, 2010; Miller et al., 2018; Stroupe, 2014). Enabling student agency for configuring shared classroom structures is a tall order and requires researchers to provide a clear account of the interactive processes and support strategies. The results of this research address this need by providing an elaborated view of how young students can enact such epistemic agency to support expansive knowledge building. The analyses of RQ1 and RQ2 provide a detailed temporal account of how the fifth-graders enacted epistemic agency for co-structuring emergent inquiry directions while at the same time forming/reforming collaborative groups.

As the analyses suggest, the co-construction of inquiry structures takes place as an emergent process, which builds on the initial, teacher-incorporated structures and shifts toward increasing student control for co-structuring joint inquiry practices. Specifically, the human body inquiry was kicked off with an anchoring activity designed by the teacher in light of the school's curriculum requirements, teaching practices and resources, and instructional time. The kick-off activity served to elicit students' diverse interests and wonderments related to human body systems. Students brought their personal interests and questions to a metacognitive meeting to formulate an initial set of wondering areas, reified using a visual artifact (see Figure 4). This artifact served as a shared structure-bearing resource (Sewell, 1992) to frame what the community needed to investigate. This structure was further used to shape the socio-epistemic context of the community's inquiry: to form interest-based groups in the classroom, to organize online discourse spaces (see Figures 1 and 2), to reflect on ongoing progress and create shared documentation of knowledge advances and challenges (see Figure 3 and Table 1). As their inquiry proceeded, giving rise to new challenges and connections, the classroom members re-imagined what they should further investigate by adapting their wondering areas (see Figures 4 and 5) and group structures, leading to an ongoing reconfiguration of student participation and collaboration (see Table 2). Students took on increasing collective responsibility and agency to advance their community's knowledge while re-configuring their knowledge building practices, as an evolving social activity system (Damsa, 2010; Zhang et al., 2009).

The above-noted temporal process of reflective structuration offers a way to rise above the tension between guidance structures and student agency that lies at the heart of the implementation of ever-unfolding science practices (Biggers & Forbes, 2012; Gutierrez & Calabrese Barton, 2015; Manz & Suárez, 2018). By engaging students in the ongoing co-construction of inquiry structures, educators can simultaneously release student epistemic agency while also devising adaptive guidance and coordination for the classroom community. In this study, the fifth-graders enacted epistemic agency through playing an important role in co-structuring shared wondering areas and collaborative groups. The co-formed wondering areas and group structures helped the teacher and her students to develop a general image of *what* they were researching, *who* was working on what, and in collaboration with *whom* in their community (cf. Schwarz et al., 2017). Using the co-constructed structures as a reference, the teacher guided her students to monitor the ongoing flow of ideas in their community, plan for deeper inquiry as individuals and groups, and make accountable and connected contributions. In the BOOK view, students shared high-quality reflection on their deepening questions within and across wondering areas and synthesized advanced understandings for collective awareness (see Table 1). The co-constructed inquiry directions and groups were not fixed but remained open for students' creative input, as they had the opportunity to expand and reframe their collective work in response to emergent needs and changing conditions (see Figure 5), reimagine personal roles, and reform collaborative groups accordingly (see Table 2). Supporting such agency is essential to enabling expansive knowledge practices in science and beyond, so students can work as codesigners of their learning pathways and respective futures (Gutierrez & Calabrese Barton, 2015; Miller et al., 2018; Sannino et al., 2016).

**4.2 Working with Co-Constructed Inquiry Areas and Groups Supports Expansive Inquiry and Collaboration**

As the analyses of RQ3 suggest, the co-constructed inquiry directions and evolving groups serve to create an supportive context for channeling student expansive knowledge building actions and interactions, such as those identified in the literature (Berland & Hammer, 2012; Berland & Reiser, 2011; Ford & Forman, 2006; Lehrer & Schauble, 2006; Manz, 2015; Varelas et al., 2007). The young students in this study identified and framed authentic problems involving ambiguity and uncertainty, with deeper problems surfacing as their inquiry progressed. Ongoing reflection on knowledge advances and gaps gave rise to new and deeper goals for their inquiry. Students worked with diverse topics, ideas and expertise to understand how the complex human body systems work together, participating in extensive dialogues and interactions with members of their own groups and those working on other inquiry areas.

As an important feature of expansive knowledge building practices, the results shed light on the process of opportunistic collaboration. While designs of collaborative learning in classrooms often involve fixed small groups that are guided by scripted procedures and roles (Fischer et al., 2013; Kirschner & Erkens, 2013), this study shows that young students can engage in opportunistic collaboration in which groups are continually adapted in response to changing knowledge goals, personal needs, and social connections. Enriching the existing studies on opportunistic collaboration (Siqin et al., 2015; Zhang et al., 2009), this study has offered a more nuanced view of how opportunistic collaboration unfolds. Opportunistic groups form through an emergent process in light of the evolving ideas, inquiry directions (questions), and connections in the whole classroom community. In the case of the eye inqiry group, when several students with related interests, experiences or materials came together to carry out interconnected work in an emerging area of inquiry, a spontaneous group started to form. They engaged in open exploration of questions and ideas, built on social acquaintance and relationships, and further co-constructed a shared framing of joint inquiry (e.g., “How do we see?”) as a wondering area. The shared framing of their overarching question provided a joint focus of inquiry to be pursued in connection with other areas in the whole community (Figure 4). Student memberships were adapted over time based on student discretion. As the initial group members (e.g., CH and ST) worked on their focal area of inquiry and shared information in the classroom and online, other students (e.g., OL) might find connections and decide to join them. As the inquiry progressed, some of the group members (e.g., AS) developed new connections with other inquiry areas and peers and eventually shifted their core inquiry foci and group connections. When they moved to other areas and formed new groups, they carried and reorchestrated their repertoire of knowledge and social connections in their new inquiry works.

Opportunist collaboration allows students to develop sustained inquiry and interactive dialogues with their close peers while also interacting with the broader interests, ideas, and peoples across the whole classroom community. For example, in the eye inquiry group, students' activities were often improvised on a day-to-day basis, integrating constructive use of readings, spontaneous experiments and observations, small group talks and whole class exchanges, and ongoing online discourse. As the analysis of the inquiry processes (e.g., inquiry thread #2) suggests, students continually built on one another's inquiry actions (e.g., questioning, idea generation, observation, synthesizing) over time within each activity episode and across different timeframes and activity settings. A member's idea-advancing move (e.g., questioning) drawing upon a specific activity or resource (e.g., reading a book) might open up opportunities for further moves to be taken up by other members using various activities and resources in the current or subsequent lesson period, stimulating new streams of conversations while revisiting and addressing earlier questions. Consistent with our observation, the eye inquirers shared similar reflection in the final interview when responding to the questions of how they had worked with their peers: "*We can tell each other what we learned*" (OL), "*come up with another theory, or learn something and we all put our knowledge together*." (CH) "*Because [they] had different information than I did. Once we put the knowledge together, we made up big theory*." (ST) Student idea interactions were further expanded through community-wide social exchanges, with permeable boundaries between the different groups. In the classroom, the eye inquirers often sat around a cluster of desks, working either as a group or as individuals with informal exchanges among themselves and with the rest of the class. Spontaneous exchange of ideas often led to improvised group activities, such as extended group talk to explore a new question or spontaneously generated experiments and observations to deepen their understanding. Their internal sharing of exciting findings sometimes attracted other classmates to join in their conversation (e.g., in inquiry thread #3b). On an ongoing basis, the eye inquirers posted their questions, ideas, and new observations in the Eyes view for online discussion (see Figure 1) and interacted with their classmates working on the related inquiry areas. Through the online discourse, students developed extensive build-on links with their peers beyond their own groups and areas (Figure 6). There were rich moments of "serendipity of encounters" (Pendleton-Jullian & Brown, 2018) when students' observations, ideas, and use of physical resources (e.g. books, models) came into an interplay to generate new inquiry directions and knowledge progress, such as the spontaneous experiments they conducted to investigate the change of pupil size (inquiry thread #3a) and how the two eyes see one image (inquiry thread #2). Research has shown that dynamic idea contacts and dialogues are essential to creative knowledge practices in real-world settings (Sawyer, 2007, 2015). This study suggests that young students can engage in such dynamic interactions for productive knowledge building.

### 4.3 The Teacher Provides Dynamic Support for Emergent Co-Structuring of Expansive Inquiry and Collaboration

This study further investigated the teacher's role to support the emergent co-structuring of student-driven inquiry and collaboration. Deepening the existing studies on dynamic teacher roles to support student epistemic agency (Cherbow & McNeill, in press; Ko & Krist, 2019; Harris et al., 2012; Manz & Suárez, 2018), the findings of this study and our related work (Tao & Zhang, 2021) show how the dynamic teacher roles may work out in a temporal and interactional context in alignment with students' role as epistemic agents. In this study, while the teacher used pre-structured activities to kick off the human body inquiry in the early phase, she increasingly engaged students as partners to co-construct inquiry directions and groups and reflect on their engagement. With the co-constructed inquiry structures in place guiding student personal participation and joint interaction, the teacher had the chance to distribute part of her role of classroom coordination to the knowledge building community, as a shared responsibility. She then could refocus her role as a co-learner to participate in the knowledge building process with her students. In a sense, she worked *in*—not simply *on*—the flow (cf. Pendleton-Jullian & Brown, 2018) of the community's inquiry: to understand what was going on in students' interactive inquiries and discourse, to recognize opportunities for deeper thinking/discourse, sense student needs of support, so as to act accordingly to turn the potential opportunities into fruitful efforts of knowledge building. While doing so, the teacher also encouraged and mentored her students to do the same, enhancing their collective responsibility to monitor the diverse ideas and inquiries in their community, act on creative opportunities, and work with the teacher and peers to co-configure productive pathways of inquiry as it unfolds. As the teacher reflected on in the final interview: "*Students are…really in charge of this (inquiry)… And there are like, small groups that are emergent from the whole class, there are common threads they can talk about. Even though everyone sees their peers to be in different things…we're all really very connected. And they were building on each other. I think it's been something that I realized goes on well when building knowledge together.*"

**5. Concluding Thoughts**

Taken as a whole, the findings show how young students may enact epistemic agency to co-structure unfolding inquiry directions and dynamic groups as their collaborative inquiry continually deepens and expands. As implications for science education research, the findings offer an elaborated account of students' epistemic agency for shaping/reshaping shared inquiry structures and conditions in the classroom as they pursue collaborative knowledge building as a community. Reflective structuration, as elaborated in this study, offers a conceptual and analytical lens to understand the temporal process by which students enact epistemic agency as a collaborative community. As a key point of analysis, research on epistemic agency for science practices need to investigate students' interactive input to co-constructing shared inquiry structures, such as to formulate shared inquiry directions and group structures in light of members' diverse interests and idea connections. The co-constructed inquiry structures provide an interpretative framing for the teacher and students to make sense of what is going on in their community (Hutchison & Hammer, 2010), monitor the ongoing flow of ideas, plan for deeper inquiry, and make accountable contributions. At the same time, the structures are not fixed but remain open, allowing students to expand and reframe the landscape of their collective work and adjust their personal and collaborative roles. Therefore, epistemic agency, as depicted in this study, goes beyond the popular notion of "learner agency" as students being able to manage their learning tasks in a self-regulated, proactive and responsible manner. Beyond carrying out assigned inquiry tasks, students with epistemic agency continually seek new problems to solve and transform knowledge building practices beyond existing expectations, frames and boundaries (Tao & Zhang, 2021). Students may pick up new challenges and develop new lines of inquiry, leverage emergent connections across different clusters of ideas, and reform group structures as needed.

Besides, this study elaborates on the process of opportunistic collaboration that supports expansive knowledge bulding practices. Instead of working in fixed small groups, students form/reform opportunistic groups to support ever-deepening inquiry. This dynamic collaboration approach can be used to support emergent knowledge goals, improvisational discourse and serendipity of idea encounters, as driving forces for creative knowledge practices in science and beyond (Knorr-Cetina, 2001; Pendleton-Jullian and Brown, 2018; Sawyer, 2007). Opportunistic collaboration may be supported using co-constructed framing of inquiry directions that guide student participation, collaboration tools that make ongoing knowledge flows visible to students (Zhang et al., 2018), and dynamic teacher support such as that elaborated in this study.

As implications for education practices, this research showcases a design strategy to develop expansive science practices in the classroom in a way that fosters students' epistemic agency. The teacher engages students as partners to co-design key aspects of collaborative inquiry as it continually unfolds. Different from prescriptive designs of inquiry projects with presequenced inquiry tasks and materials, reflective structuration implies "designing for emergence" (Pendleton-Jullian & Brown, 2018). The teacher can first provide an entry point and an open space for students to participate in exploratory inquiry and participation. Then, as students participate in the open space, the teacher can discover emergent "interest trails" (e.g., high-potential questions and ideas), upon which productive directions and pathways of inquiry may be co-constructed with students. The co-constructed inquiry structures provide a guidance framework for students to carry out purposeful inquiry and dynamic collaboration, informing decisions about what they should investigate, how, and by/with whom. Such epistemic choices are continually reflected upon and reworked by classroom members as their knowledge work evolves, leading to the ongoing adaption of inquiry structures that open new opportunities for further inquiry and knowledge building. The teacher needs to pay close attention to what is going on in the classroom, discover emergent inquiry directions and connections, and seize on opportunities to catalyze deeper inquiry and collaboration in existing areas or nurture new lines of inquiry possibly beyond the teacher's initial plan. This approach of emergent co-design may be used to develop open classroom configurations that foster student agency for shaping and re-shaping their learning processes and pathways (González-Howard & McNeill, 2020; Gutiérrez & Calabrese Barton, 2015; Ko & Krist, 2019; Manz & Suárez, 2018; Miller et al., 2018).

As a limitation, this study only analyzed a single classroom case that used the Knowledge Building pedagogy in grade 5 science. We hope that the findings provide a stepstone for thinking about future research and classroom innovations that foster student epistemic agency for creative science practices.

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**Data Availability Statement**

The anonymized data that support the analyses of this study are available from the first author upon reasonable request. The data are not publicly available due to privacy or ethical restrictions.

**References**

Archer, M. S. (1982). Morphogenesis versus structuration: On combing structure and action. *British Journal of Sociology, 33*, 455-483.

Berland, L. K., & Hammer, D. (2012). Framing for scientific argumentation. *Journal of Research in Science Teaching, 49*(1), 68–94.

Berland, L. K., & Reiser, B. J. (2011). Classroom communities' adaptations of the practice of scientific argumentation. *Science Education, 95*(2), 191–216.

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching, 53*(7), 1082–1112. https://doi.org/10.1002/tea.21257

Bielaczyc, K., & Collins, A. (2006). Technology as a catalyst for fostering knowledge-creating communities. In A. M. O'Donnell, C. E. Hmelo-Silver, & G. Erkens (Eds.), *Collaborative learning, reasoning, and technology* (pp. 37–60). Mahwah NJ: Lawrence Erlbaum Associates.

Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, V. D., Annetta, L. A., & Granger, E. M. (2010). Is inquiry possible in light of accountability?: A quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction. *Science Education, 94*(4), 577–616. https://doi.org/10.1002/sce.20390

Bodemer, D., Janssen, J., & Schnaubert, L. (2018). Group awareness tools for computer-supported collaborative learning. In F. Fischer, C. E. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International handbook of the learning sciences* (pp. 351–358). New York, NY: Routledge.

Bourdieu, P. (1977). Cultural reproduction and social reproduction. In J. Karabel & A.H. Hasley (Eds.), *Power and ideology in education* (pp. 487-511). New York: Oxford University Press.

Biggers, M., & Forbes, C. T. (2012). Balancing teacher and student roles in elementary classrooms: Preservice elementary teachers' learning about the inquiry continuum. *International Journal of Science Education, 34*(14), 2205– 2229.

Calabrese Barton, A., & Tan, E. (2010). We Be Burnin'! Agency, Identity, and Science Learning. J*ournal of the Learning Sciences, 19*(2), 187-229. https://doi.org/10.1080/10508400903530044

Carolan, B. V. (2014). *Social network analyses and education: Theory, methods & applications*. Thousand Oaks, CA: SAGE.

Chatzkel, J. L. (2003). *Knowledge capital*. New York: Oxford University Press.

Chen, B., & Hong, H. Y. (2016). Schools as Knowledge-Building Organizations: Thirty Years of Design Research. Educational Psychologist, 51(2), 266-288.

Chen, Y., Benus, M. J., & Hernandez, J. (2019). Managing uncertainty in scientific argumentation. *Science Education*, *103*(5), 1235–1276. https://doi.org/10.1002/sce.21527

Cherbow, K., & McNeill, K. (2022). Planning for student-driven discussions: A revelatory case of curricular sensemaking for epistemic agency. *Journal of the Learning Sciences*. https://doi.org/10.1080/10508406.2021.2024433

Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. J*ournal of the Learning Sciences, 6*, 271-315.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*(2), 175–218.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *Journal of the Learning Sciences, 13*(1), 15-42.

Damşa, C. I., Kirschner, P. A., Andriessen, J. E. B., Erkens, G., & Sins, P. H. M. (2010) Shared epistemic agency: An empirical study of an emergent construct. *Journal of the Learning Sciences, 19* (2), 143-186. DOI: 10.1080/10508401003708381

Damşa, C., Nerland, M., & Andreadakis, Z. E. (2019). An ecological perspective on learner-constructed learning spaces. *British Journal of Educational Technology, 50* (5), 2075-2089. https://doi.org/10.1111/bjet.12855

De Wever, B., Schellens, T., Van Keer, H., & Valcke, M. (2008). Structuring asynchronous discussion groups by introducing roles: Do students act in line with assigned roles? *Small Group Research*, *39*(6), 770–794. https://doi.org/10.1177/1046496408323227

Dunbar, K. (1997). How scientists think: Online creativity and conceptual change in science. In T. B. Ward, S. M. Smith & S. Vaid (Eds.), *Conceptual structures and processes: Emergence, discovery and change* (pp. 461-493). Washington, DC: APA Press.

Duncan, R. G., & Chinn, C. (Eds.). (2021). *International handbook of inquiry and learning*. New York: Routledge.

Duschl, R. A. (2020). Practical reasoning and decision making in science: Struggles for truth. *Educational Psychologist, 55*(3), 187–192. https://doi.org/10.1080/00461520.2020.1784735

Engeström, Y. (2015). *Learning by expanding: An activity-theoretical approach to developmental research* (2nd ed.). Cambridge, UK: Cambridge University Press.

Engle R. A. (2006). Framing interactions to foster generative learning: A situative explanation of transfer in a community of learners classroom. *Journal of the Learning Sciences, 15*, 451-498. DOI: 10.1207/s15327809jls1504_2

Engle, R. A., Lam, D. P., Meyer, X. S., & Nix, S. E. (2012). How does expansive framing promote transfer? Several proposed explanations and a research agenda for investigating them. *Educational Psychologist, 47*(3), 215–231. https://doi.org/10.1080/00461520.2012.695678

Engle, R., & Conant, F. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction, 20,* 399 – 483.

Fischer, F., Kollar, I., Stegmann, K., & Wecker, C. (2013). Toward a script theory of guidance in computer-supported collaborative learning. *Educational Psychologist, 48*(1), 56–66. https://doi.org/10.1080/00461520.2012.748005

Ford, M., & Forman, E. (2006). Redefining disciplinary learning in classroom contexts. *Review of Research in Education, 30*, 1 – 32.

Giddens, A. (1984). *The constitution of society*. Cambridge, Oxford, UK: Polity Press.

Goodwin, C. (2017). *Co-operative action*. New York, NY: Cambridge University Press.

Gloor, P. A. (2006). *Swarm creativity: Competitive advantage through collaborative innovation networks*. Oxford, England: Oxford University Press.

González-Howard, M., & McNeill, K. L. (2020). Acting with epistemic agency: Characterizing student critique during argumentation discussions. *Science Education, 104*(6), 953–982. https://doi.org/10.1002/sce.21592

Green, J., & Bridges, S. (2018). Interactional ethnography. In F. Fischer, C.E. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International handbook of the learning sciences* (pp. 475-488). New York, NY: Routledge.

Green, J., Skukauskaite, A., Dixon, C. & Cordova, R. (2007). Epistemological issues in the analysis of video records: Interactional ethnography as a logic of inquiry. In R. Goldman, R. Pea, , R. Barron, & S. Derry (Eds). *Video research in the learning sciences* (pp. 115-132). Mahwah, NJ: Lawrence Erlbaum Associates.

Greetz, C. (1973). *The interpretation of culture*. New York, NY: Basic Books.

Gutiérrez, K. D., & Calabrese Barton, A. (2015). The possibilities and limits of the structure-agency dialectic in advancing science for all. *Journal of Research in Science Teaching, 52*(4), 574–583. https://doi.org/10.1002/tea.21229

Hakkarainen, K. (2009). A knowledge-practice perspective on technology-mediated learning. *International Journal of Computer-Supported Collaborative Learning, 4*, 213-231.

Harris, C., Phillips, R., & Penuel, W. (2012). Examining teachers' instructional moves aimed at developing students' ideas and questions in learner-centered science classrooms. *Journal of Science Teacher Education, 23*(7), 769– 788.

Hutchison, P., & Hammer, D. (2010). Attending to student epistemological framing in a science classroom. *Science Education, 94*, 506-524. https://doi.org/10.1002/sce.20373

Heinimäki, O.-P., Volet, S., Jones, C., Laakkonen, E., & Vauras, M. (2021). Student participatory role profiles in collaborative science learning: Relation of within-group configurations of role profiles and achievement. *Learning, Culture and Social Interaction, 30*, 100539. https://doi.org/10.1016/j.lcsi.2021.100539

Kirschner, P. A., & Erkens, G. (2013). Toward a framework for CSCL research. *Educational Psychologist, 48*(1), 1–8. https://doi.org/10.1080/00461520.2012.750227

Knorr-Cetina, K. (2001). Objectual practice. In T. R. Schatzki, K. Knorr-Cetina, & E. Savigny (Eds.), *The practice turn in contemporary theory* (pp. 175-188). London, UK: Routledge.

Ko, M. M., & Krist, C. (2019). Opening up curricula to redistribute epistemic agency: A framework for supporting science teaching. *Science Education, 103*(4), 979–1010. https://doi.org/10.1002/sce.21511

Lehrer, R., & Schauble, L. (2006). Scientific thinking and science literacy. In W. Damon, R. Lerner, K. A. Renninger, & I. E. Sigel (Eds.), Handbook of child psychology: Child psychology in practice (6th ed., Vol. 4, pp. 153 – 196). Hoboken, NJ: Wiley.

Manz, E. (2015). Resistance and the development of scientific practice: Designing the mangle into science instruction. *Cognition and Instruction, 33*(2), 89–124. https://doi.org/10.1080/07370008.2014.1000490

Manz, E., & Suárez, E. (2018). Supporting teachers to negotiate uncertainty for science, students, and teaching. *Science Education, 102*(4), 771–795. https://doi.org/10.1002/sce.21343

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards.

*Journal of Research in Science Teaching, 55*(7), 1053–1075. https://doi.org/10.1002/tea.21459

Mitchell, C. (1984). Case studies. In R. Ellen (Ed.), *Ethnographic research: A guide to general conduct* (pp. 237-241). London: Academic Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by state*s. National Academies Press. https://doi.org/10.17226/18290

Park, H. & Zhang, J. (2019). Reflective Assessment for Idea Improvement Through Collective Concept Mapping. In Lund, K., Niccolai, G. P., Lavoué, E., Hmelo-Silver, C., Gweon, G., & Baker, M. (Eds.), *A Wide Lens: Combining Embodied, Enactive, Extended, and Embedded Learning in Collaborative Settings, 13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019, Volume 2* (pp. 624-627). Lyon, France: International Society of the Learning Sciences.

Pendleton-Jullian, A. M., & Brown, J. S. (2018). *Design unbound: Designing for emergence in a white water world*. Cambridge, MA: The MIT Press.

Rienties, B., & Tempelaar, D. (2018). Turning groups inside out: A Social network perspective. *Journal of the Learning Sciences, 27*(4), 550–579. https://doi.org/10.1080/10508406.2017.1398652

Sannino, A., Engeström, Y., & Lemos, M. (2016). Formative interventions for expansive learning and transformative agency. *Journal of the Learning Sciences, 25* (4), 599-633. DOI: 10.1080/10508406.2016.1204547

Sawyer, R. K. (2005). *Social emergence: Societies as complex systems*. Cambridge University Press.

Sawyer, R. K. (2007). *Group genius: The creative power of collaboration*. New York, NY: Cambridge University Press.

Sawyer, R. K. (2015). A call to action: The challenges of creative teaching and learning. *Teachers College Record*, *117*(10), 1-34.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal education in a knowledge society*, (pp. 76-98). Chicago: Open Court.

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *Journal of the Learning Sciences*, *1*(1), 37-68.

Scardamalia, M., & Bereiter, C. (2014). Knowledge building and knowledge creation: Theory, pedagogy, and technology. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (2nd ed., pp. 397–417). Cambridge University Press. https://doi.org/10.1017/CBO9781139519526.025

Schwarz, C. V., Passmore, C., & Reiser, B. (Eds.). (2017). *Helping students make sense of the world using Next Generation Science and Engineering Practices*. Arlington, VA: NSTA Press.

Seitamaa-Hakkarainen, P. (2022). Creative expansion of knowledge-creating learning. *Journal of the Learning Sciences*, 31(1). https://doi.org/10.1080/10508406.2022.2029105

Sewell, W. H. Jr. (1992). A theory of structure: Duality, agency, and transformation. American *Journal of Sociology, 98*, 1-29.

Siqin, T., van Aalst, J., & Chu, S. K. W. (2015). Fixed group and opportunistic collaboration in a CSCL environment. *International Journal of Computer-Supported Collaborative Learning, 10*(2), 161-181.

Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education, 98*(3), 487–516. https://doi.org/10.1002/sce.21112

Tan, S.C., Chan, C., Bielaczyc, K., Ma, L., Scardamalia, M., & Bereiter, C. (2021). Knowledge building: aligning education with needs for knowledge creation in the digital age. *Educational Technology Research and Dev*elopment, *69***,** 2243–2266.

Tao, D., & Zhang, J. (2018). Forming shared inquiry structures to support knowledge building in a grade 5 community. *Instructional Science, 46*, 563-593.

Tao, D., & Zhang, J. (2021). Agency to Transform: How Did a Grade 5 Community Co-Configure Dynamic Knowledge Building Practices in a Yearlong Science Inquiry? *International Journal of Computer-Supported Collaborative Learning, 16,* 403–434. https://doi.org/10.1007/s11412-021-09353-7

Tsovaltzi, D., Weinberger, A., Schmitt, L., Bellhäuser, H., Müller, A., et al. (2019). Group formation in the digital age: Relevant characteristics, their diagnosis, and combination for productive collaboration. In Lund, K., Niccolai, G. P., Lavoué, E., Hmelo-Silver, C., Gweon, G., & Baker, M. (Eds.), *A wide lens: Combining embodied, enactive, extended, and embedded learning in collaborative settings*, 13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019, Volume 2 (pp. 719-726). Lyon, France: International Society of the Learning Sciences.

Varelas, M., Pappas, C. C., Kane, J. M., Arsenault, A., Hankes, J., & Cowan, B. M. (2007). Urban primary-grade children think and talk science: Curricular and instructional practices that nurture participation and argumentation. Science Education, 92(1), 65– 95.

Varelas, M., Settlage, J., & Mensah, F. M. (2015). Explorations of the structure-agency dialectic as a tool for framing equity in science education. *Journal of Research in Science Teaching, 52*(4), 439-447.

Wageman, R., Gardner, H., & Mortensen, M. (2012). The changing ecology of teams: New directions for teams research. *Journal of Organizational Behavior, 33*(3), 301–315. https://doi.org/10.1002/job.1775

Williams, W. M., & Yang, L. T. (1999). Organizational creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 373-391). Cambridge, UK: Cambridge University Press.

Yuan, G., & Zhang, J. (2019). Connecting Knowledge Spaces: Enabling Cross-Community Knowledge Building through Boundary Objects. *British Journal of Educational Technology, 50* (5), 2144–2161.

Zhang, J., Hong, H.-Y., Scardamalia, M., Teo, C., & Morley, E. (2011). Sustaining knowledge building as a principle-based innovation at an elementary school. *Journal of the Learning Sciences, 20*, 262-307.

Zhang, J., Scardamalia, M., Lamon, M., Messina, R., & Reeve, R. (2007). Socio-cognitive dynamics of knowledge building in the work of nine- and ten-year-olds. *Educational Technology Research and Development*, *55*, 117-145.

Zhang, J., Scardamalia, M., Reeve, R., & Messina, R. (2009). Designs for collective cognitive responsibility in knowledge building communities. *Journal of the Learning Sciences, 18*, 7-44.

Zhang, J., Tao, D., Chen, M.-H., Sun, Y., Judson, D., & Naqvi, S. (2018). Co-organizing the collective journey of inquiry with idea thread mapper. *Journal of the Learning Sciences*, *27*, 390-430.

Zhang, J., Yuan, G., & Bogouslavsky, M. (2020). Give student ideas a larger stage: Support cross-community interaction for knowledge building. *International Journal of Computer-Supported Collaborative Learning,15(4)*, 389–410. https://doi.org/10.1007/s11412-020-09332-4

Figures and Tables

Figures

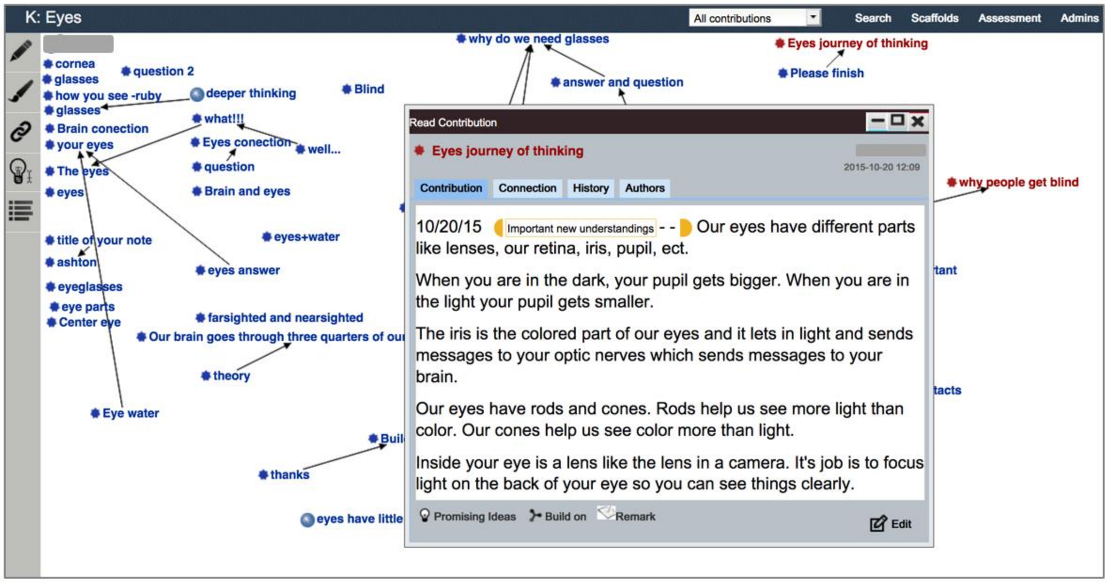


*Figure 1*. Students’ knowledge building discourse in a Knowledge Forum view (workspace) focused on the function of eyes. Each dot represents a note, and a link connecting two notes shows a build-on connection. The opened note was written by a student in the second month of the human body inquiry to reflect on the new understandings developed in this view.

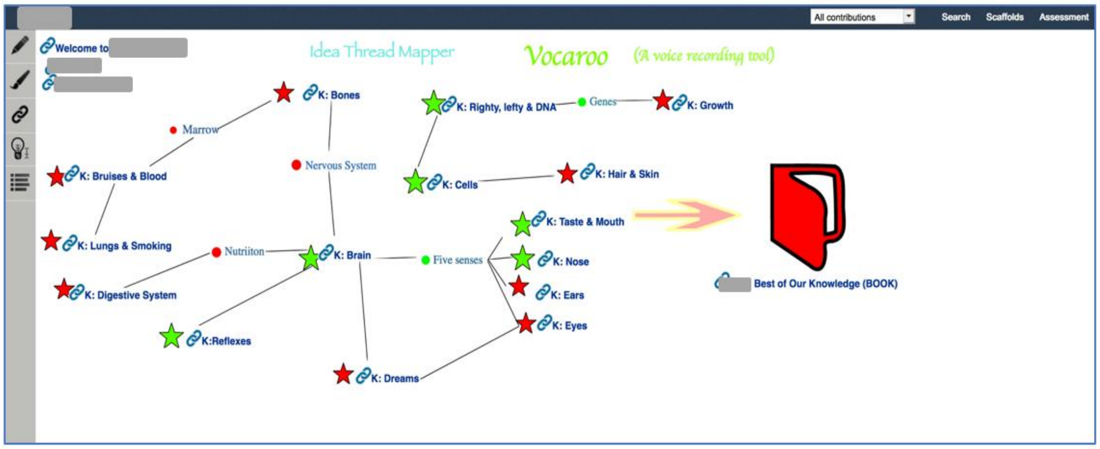



*Figure 2*. The home view for the human body inquiry that organized the hyperlinks to the specialized views, which were created over time focusing on the emergent wondering areas.

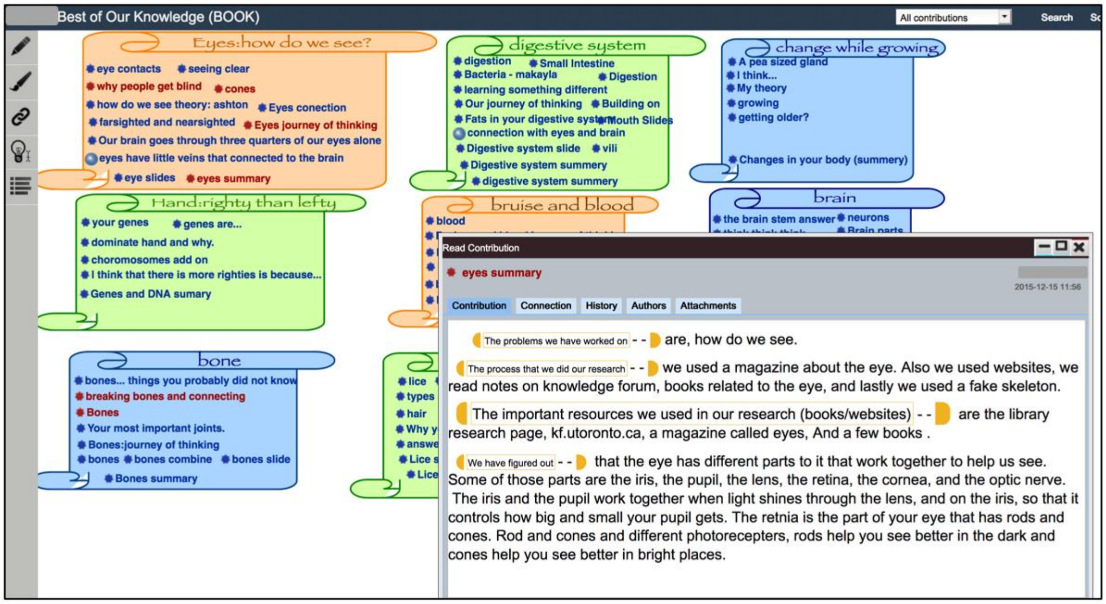
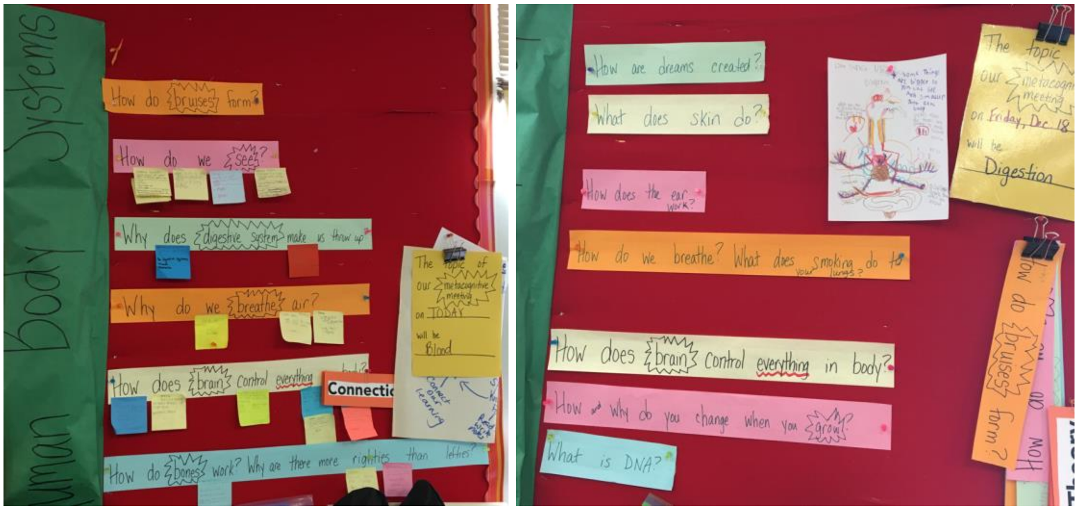



*Figure 3.* The “Best of Our Knowledge (BOOK)” view where students shared core ideas gained in each area, reflected on their journey of inquiry, and wrote reflective summary notes. The opened note shows the summary of the eye inquiry.




(a) (b)

*Figure 4.* The initial (a) and adapted (b) wondering areas.

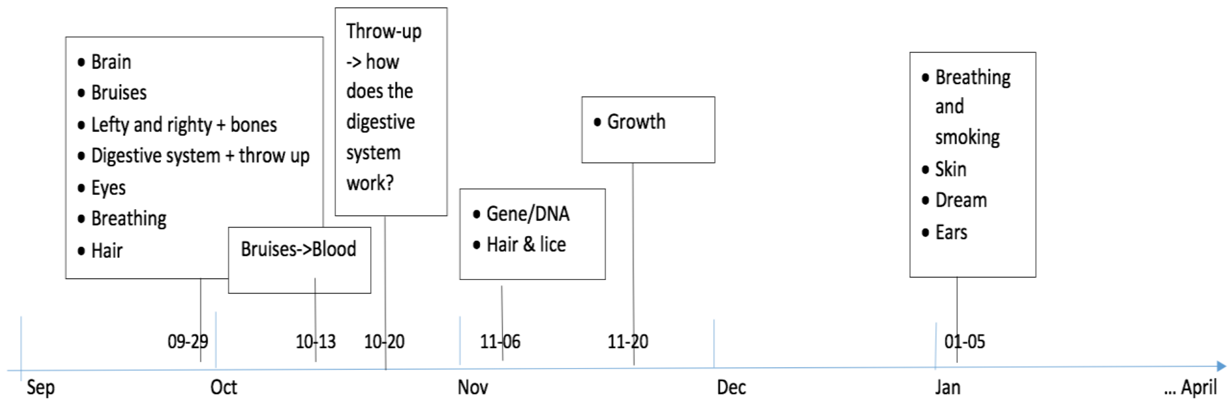
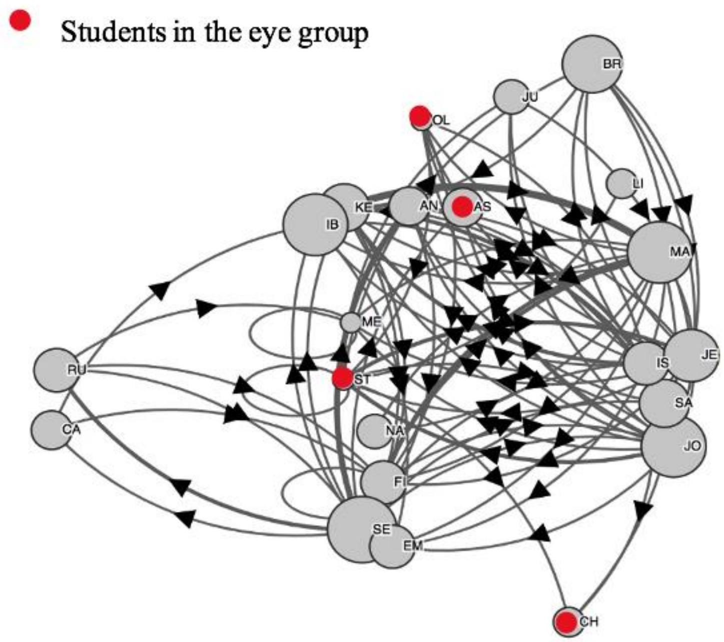
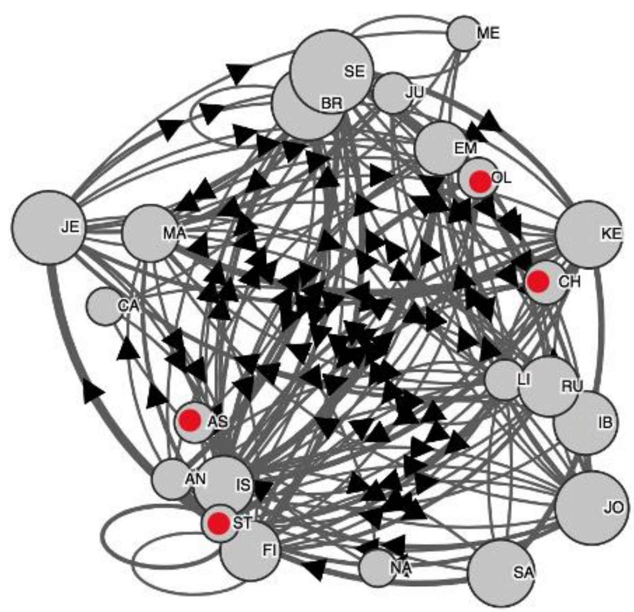



*Figure 5.* The formulation and adaptation of collective inquiry directions over time.




(a) During October to December




(b) During the whole inquiry

*Figure 6.* Social network analysis of who had built on whose notes during the human body inquiry.

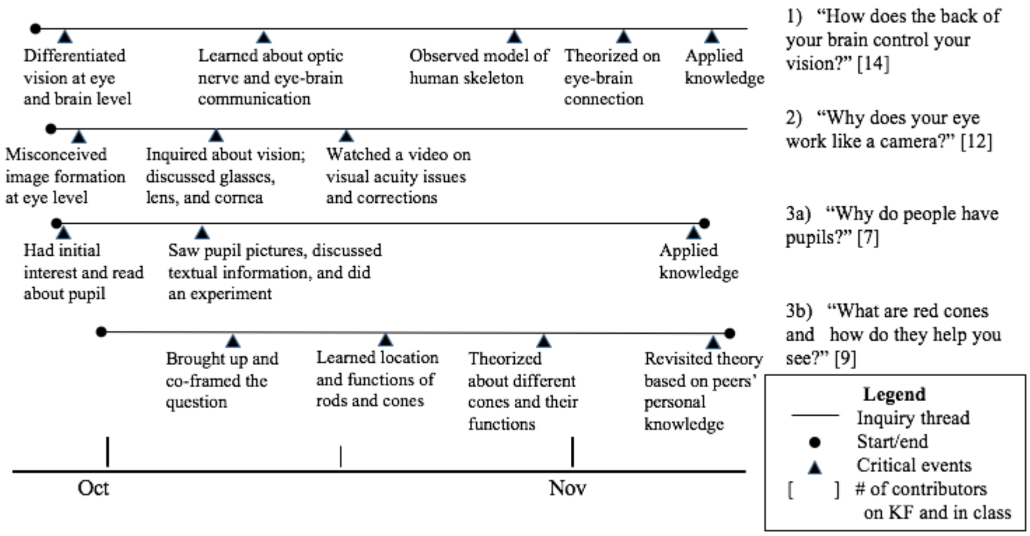



*Figure 7*. Tracing core questions, inquiry activities and progress in understanding how people see.

Tables

Table 1

*Content analysis of students' reflection notes in the BOOK view*

| Dimension of coding | Category | Frequency |
|---|---|---|
| Coding of inquiry questions | Fact-seeking | 7 |
| | vs. | |
| | Explanation-seeking | 23 |
| | Single-area question | 15 |
| | vs. | |
| | Cross-area question | 15 |
| Coding of ideas synthesized in each note: | | |
| Scientific level coding | 1. Pre-scientific | 0 |
| | 2. Hybrid | 0 |
| | 3. Basically Scientific | 2 |
| | 4. Scientific | 13 |
| Complexity level coding | Unelaborated Fact | 0 |
| | Elaborated Fact | 6 |
| | Unelaborated Explanation | 2 |
| | Elaborated Explanation | 7 |

Table 2

*Tracing of each student's inquiry focus on the various wondering areas*

| Student | Initial area identified on Sept 29 | Oct | Nov | Dec | Jan and after |
|---|---|---|---|---|---|
| **BR** | Bones | (cont.) | (cont.) | (cont.) | Ears |
| **JE** | Lefty and righty | Lefty and righty + bones | Gene & DNA | (cont.) | (cont.) |
| **JU** | Lefty and righty | Lefty and righty + bones | Gene & DNA | (cont.) | (cont.) |
| **AN** | Brain | (cont.) | (cont.) | (cont.) | (cont.) |
| **SA** | Brain | (cont.) | (cont.) | (cont.) | Ears |
| **CA** | Brain | Bruises & blood | (cont.) | (cont.) | Breath & Smoking |
| **JO** | Brain | (cont.) | (cont.) | (cont.) | Ears |
| **KE** | Brain | (cont.) | Hair & lice | (cont.) | Skin |
| **RU** | Brain | (cont.) | Gene & DNA; Growth | (cont.) | (cont.) |
| **SE** | Brain | (cont.) | Gene & DNA; Growth | (cont.) | (cont.) |
| **IS** | Brain | (cont.) | Hair & lice | (cont.) | Skin |
| **MA** | Digestive system + Throw up | Digestive system | (cont.) | (cont.) | (cont.) |
| **IB** | Digestive system + Throw up | Digestive system | (cont.) | (cont.) | Breathing & smoking |
| **NA** | Digestive system + Throw up | Digestive system | (cont.) | (cont.) | Dream |
| **ME** | Hair | Digestive system | (cont.) | (cont.) | Dream |
| **FI** | Bruises | Blood | (cont.) | (cont.) | (cont.) |
| **EM** | Breathing | (cont.) | Hair & lice | (cont.) | Skin |
| **LI** | Breathing | (cont.) | (cont.) | (cont.) | Brain, breathing |
| **ST** | Eyes | (cont.) | (cont.) | (cont.) | Dreams |
| **OL** | Eyes | (cont.) | (cont.) | (cont.) | Dreams, brain, blood |
| **AS** | Eyes | (cont.) | Brain | (cont.) | Ears/nose |
| **CH** | Eyes | (cont.) | (cont.) | (cont.) | Dreams |

Table 3

*Student participation in the online discourse focusing on the co-identified inquiry* areas

| Knowledge Forum views (areas) | Number of authors | Number of notes | Average words per note | Duration of discourse (Month/Day/Year) |
|---|---|---|---|---|
| Bruises & Blood | 17 | 64 | 24.7 | 10/9/2015 - 4/14/2016 |
| Eyes | 16 | 56 | 21.0 | 10/9/2015 - 3/22/2016 |
| Digestive System | 9 | 39 | 25.6 | 10/9/2015 - 1/29/2016 |
| Lungs (breathing) & Smoking | 10 | 40 | 28.9 | 10/9/2015 - 3/29/2016 |
| Brain | 16 | 85 | 22.9 | 10/9/2015 - 3/29/2016 |
| Bones | 12 | 34 | 25.5 | 10/9/2015 - 4/8/2016 |
| Righty, Lefty & DNA | 10 | 40 | 39.5 | 10/9/2015 - 3/29/2016 |
| Hair & Skin | 11 | 29 | 23.4 | 10/9/2015 - 3/29/2016 |
| Growth | 7 | 22 | 33.5 | 11/20/2015 - 3/29/2016 |
| Dreams | 9 | 16 | 28.0 | 1/19/2016 - 3/18/2016 |
| Reflexes | 10 | 34 | 30.4 | 10/9/2015 - 3/29/2016 |
| Ears | 7 | 28 | 29.9 | 1/12/2016 - 4/14/2016 |
| Cells | 4 | 10 | 28 | 2/26/2016 - 4/1/2016 |
| Nose | 2 | 4 | 17.5 | 3/18/2016 - 3/18/2016 |
| Taste & Mouth | 6 | 19 | 37.1 | 3/18/2016 - 3/29/2016 |

*Note:* The views are listed based on time of creation. Some of the views were renamed (e.g., Righty, Lefty & DNA) during the inquiry to include a new focus. Some of the views that were created at a later time (e.g. Reflexes, Growth) included the relevant notes selectively copied from the prior views.