Collaborative Productivity as Self-Sustaining Processes in a Grade 4 Knowledge Building Community

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Abstract: This study elaborates collaborative productivity as self-sustaining processes along with the role of the teacher in a knowledge building community. The participants were 22 fourth-graders, who investigated light over a three-month period facilitated by a veteran teacher with the support of Knowledge Forum®. Content analysis of the students' portfolios indicates significant advancement of understanding. Qualitative analysis of classroom videos, online discourse, and the teacher's reflection journal identifies community interactions and teacher scaffolding related to four interrelated processes. These include: (a) accumulating a highly variable stock of information and ideas and mobilizing information connection; (b) sustained, incremental idea development; (c) critical examination and selection of ideas; and (d) distributed emergent control. These processes elaborate self-organization mechanisms underpinning collaborative productivity, informing new ways to scaffold knowledge building.

Introduction

With knowledge-based organizations pervading a knowledge economy and society, education is facing an unprecedented demand of preparing students for collaborative and creative knowledge practices. Various inquiry-based collaborative learning programs have emerged to achieve high-level collaborative productivity in a learning community. Students engage in productive sharing, conversation, and collaborative problem solving that lead to deep understanding and advancement of collective knowledge (Barron & Darling-Hammond, 2008; Hmelo-Silver & Barrows, 2008). Efforts to explain and support collaborative productivity often focus on the teacher/designer's role in charting, organizing, and guiding the processes, with student collaborating in fixed groups following specific scripts. This focus on "strong leader" is further heightened by the argument that "minimally guided teaching techniques" do not work (Sweller et al., 2007). Alternative to this "strong leader" explanation is a self-organization perspective: collaborative productivity emerges from complex, distributed interactions with the teacher as an important participant; small intellectual input from the members builds on one another to enable increasingly complex work and emergent progress. This self-organization perspective gains support from the recent studies on creative research teams and professional communities (Dunbar, 1997; Sawyer, 2007). In line with these studies, our recent design research traced the improvement of knowledge building in a Grade 4 classroom. Over three years, the designs evolved from fixed-group collaboration that involved extensive teacher-coordination to distributed, opportunistic collaboration. The third year design led to most productive knowledge advancement (Zhang et al., 2009). The present study analyzes an extended iteration of the above design experiment. The goal is to provide an elaborated account of collaborative productivity as self-sustaining processes, which will inform new and expanded ways to scaffold knowledge building.

Our exploration of collaborative productivity as self-sustaining processes was inspired by recent research on creative communities, such as productive research labs (Dunbar, 1997) and innovative professional communities (Engestrom, 2008). A creative community works as a system that is further embedded in the larger systems in a field (Csikszentmihalyi, 1999). Collaborative knowledge creation in these communities unfolds as self-organizing and emergent processes. "[T]he most innovative teams are those that can restructure themselves in response to unexpected shifts in the environment; they don't need a strong leader to tell them what to do." (Sawyer, 2007, p. 17) The mechanism of self-organization "is basically the combination of an evolutionary raw material—a highly variable stock of information from which to select possible patterns—and a means for experimentation, for selecting and testing new patterns." (Meadows, 1999, p.15) In light of the notion of self-organization, we synthesize four essential processes that sustain knowledge creation drawing on the literature on creativity and knowledge creation.

(a) Accumulating a highly variable stock of information and ideas, with dynamic information flow. Creativity emerges when individuals, often working in teams, produce novel variations to the domain that are recognized by the field composed of peer workers (Csikszentmihalyi, 1999). Each domain (e.g., physics) evolves a public knowledge base representing the state-of-the-art understanding (Bereiter, 2002). The public knowledge space gives knowledge and ideas an out-in-the-world existence (e.g., in books). The current knowledge base is the evolutionary outcome of the past work and meanwhile thinking resources and devices for future advancement, with new advances rooted in the past and further informing ever deeper inquiries.

(b) Positive loops fueling idea generation and development: Positive feedback loops are self-reinforcing, with the output of one operation becoming the input to another. As Dunbar (1997) observed in high-performing research labs, researchers perform cognitive operations and pass the results on to peers, who then use the results as the input to further cognitive operations to create new theories and experiments. A series of small operations may lead to major, often unexpected advances, which often cannot be attributed to any individual. As a part of the positive loops, the knowledge gained about a topic helps knowledge workers to further identify what is not known and ask deeper questions (Miyake & Norman, 1979), which lead to further actions to advance knowledge (Bereiter & Scardamalia, 1993).

(c) Negative loops that enable critical examination and selection of ideas. Positive loops in a creative system need to be coupled with, and slowed down by, self-correcting negative feedback loops in order to keep important system states within safe bounds (Meadows, 1999). In academia, the negative loop is partly played out through blinded peer review and critical academic discourse. The specific criteria used to judge whether a contribution is an improvement/advancement differ across domains. Such criteria and related rules of knowledge work are further internalized by individuals and become a part of their reflective thinking and discourse, so that they can make smart decisions to tease out good ideas from bad ones and choose the most promising ideas to work on in a way that can be accepted by peers (Csikszentmihalyi, 1999; Sternberg, 2003).

(d) Distributed emergent control. Innovative teams perform spontaneously (Sawyer, 2007). Team members take on high-level collective cognitive responsibility: They collaboratively monitor their progress and emergent goals, develop and refine work processes and procedures, and group and re-group in the service of the emergent needs (Chatzkel, 2003). They invent and adopt various knowledge tools and artifacts to support their productivity and expand the scope and sophistication of thinking (Hakkarainen, 2009). They critically reflect on the social norms that specify accepted ways of conducting research and other knowledge practices, adjust existing norms, and strive for new paradigms as needed (c.f. Sternberg, 2003).

Using the self-organization mechanisms as a lens, this study views into a knowledge building community to understand how collaborative productivity occurs and can be enabled. In a knowledge building community, students engage in continuous idea improvement to advance the state of the art of the community's knowledge, mirroring the socio-cognitive dynamics of knowledge creation in the real world (Bereiter, 2002; Scardamalia, 2002). This process is augmented through technology-based environments such as Knowledge Forum, which provides a communal knowledge space and related interaction tools for knowledge building discourse (see Scardamalia, 2004). This study analyzes the knowledge building work of a Grade 4 classroom facilitated by a highly accomplished teacher. The research questions include: (a) To what extent is the knowledge building community productive, gauged based on communal and individual knowledge advancement? (b) What are the essential community interactions that sustain productive knowledge building? (c) What role does the teacher play in support of the above community dynamics?

Method

Participants

The participants were a class of 22 fourth-graders and their teacher at an elementary school in downtown Toronto. This study analyzes their knowledge building work in optics conducted over a three-month period supported by Knowledge Forum. The students had been using Knowledge Forum to conduct knowledge building since Grade 1. The teacher had accumulated strong expertise in facilitating knowledge building. An earlier study analyzed his three-year design experiment on improving classroom designs for knowledge building in optics, with significant improvement found each year (Zhang et al., 2009).

The Knowledge Building Implementation

The optics inquiry was conducted in line with the knowledge building principles (Scardamalia, 2002). The teacher particularly focused on enhancing student collective responsibility for advancing community knowledge. Instead of having students work in fixed small groups, the teacher adopted an opportunistic collaboration design that encouraged students to define and elaborate progressive inquiry goals and, accordingly, adapt their participation structures over time (Zhang et al., 2009). As a result, the knowledge building process involved a dynamic flow between individual inquiry, small group work, and whole-class conversations and allowed students to group and re-group spontaneously based on their evolving goals. The students engaged in knowledge building discourse in Knowledge Forum to contribute and improve their ideas, mirroring and extending their discourse in the classroom. Their idea improvement was further supported by constructive use of authoritative sources (e.g., books) and experimental work. Student ideas, problems, data, and reading information were contributed to Knowledge Forum for sustained online discourse.

Data Analyses

To analyze the growth of the community's knowledge space, we traced the online discourse in the seven views (workspaces) to identify progressive questions and ideas and, then, compared the questions and ideas against the curriculum guidelines. Individual knowledge growth was further assessed based on their portfolio notes. Each student wrote three portfolio notes online that summarized their understanding of light in the first, second, and third month of the inquiry, respectively. The analysis first looked at whether a portfolio note addressed each of the eight focal knowledge goals identified by the community (e.g. how lenses work). Following content analysis (Chi, 1997), student writing related to each goal was then coded based on two four-point scales (Zhang et al., 2007): (a) scientific sophistication (1 - pre-scientific, 2 - hybrid, 3 - basically scientific, and 4 - scientific) and (b) epistemic complexity (1 - unelaborated facts, 2 – elaborated facts, 3 – unelaborated explanations, and 4 - elaborated explanations), measuring effort to produce not only descriptions of the material world but theoretical explanations of hidden mechanisms (Salmon, 1984). Two raters independently coded 12 portfolio notes to assess inter-rater reliability, with full agreement for the coding of knowledge goals/themes, *Cohen's Kappa* = .83 for scientific sophistication, *Cohen's Kappa* = .75 for epistemic complexity.

We analyzed classroom video transcriptions, online discourse, and the teacher's reflection journal to identify community interactions and teacher scaffolding that had sustained productive knowledge building. The analysis integrated multiple levels and timescales, with holistic analysis of the whole initiative and detailed analysis of activity components informing each other (Lemke, 2000). In the first phase, the focus was on the community's three-month inquiry, as a whole, to understand how it started and evolved and its changing conceptual landscape. In the second phase, the focus was on each videotaped classroom episode, such as a whole-class conversation, a small group activity, or a computer lab session, to identify its focus, context, storyline, and connections with other episodes. In the final phase of detailed analysis, the focus was on each conversation turn in an episode to understand the nature of the discourse move in relation to its preceding and following conversation as well as the storyline of the episode identified in Phase 2. A more narrow approach to conversation analysis (Sawyer, 2006) was used to identify patterns through an emergent inductive process (Strauss & Corbin, 1998) without applying a predefined coding scheme and counting each code. Specifically, we read and re-read the transcriptions and coded specific moves (e.g., asking a challenging question about a peer's idea, providing evidence) represented by different conversation turns, with the speaker of each turn identified as either a student or the teacher. We then searched for connections across the specific codes in light of the contexts of the episodes and the evolution of the whole inquiry, and aggregated the codes into fewer, more encompassing themes, representing community-level (system-level) processes sustaining knowledge building. Each theme involved multiple sub-themes, with the encompassed specific moves of the teacher and those of the students considered side by side. The initial themes and sub-themes were then refined, elaborated, and validated through theme to theme, theme to data, data to data comparison, including triangulating the identified themes and sub-themes to the analysis of the teachers' reflection journals and the online discourse.

Results

To What Extent is the Knowledge Building Community Productive?

Tracing the online discourse helped to understand the conceptual scope and depth of the community knowledge space. Over the three months, a total of 168 notes (excluding the 66 portfolio notes) were created by the community in several views in Knowledge Forum. In each view, the students identified deeper questions leading to progress in understanding. For example, in the view of "Colors of Light and Rainbows," the students progressively examined how rainbows are created, why the colors are always in the same order, primary and secondary colors, the nature of white light, and how we see colored objects. The student discourse addressed all the expectations for Grade 4 in the Ontario Curriculum and further led the students to understanding many issues expected for Grades 6 and 8, such as light waves, color vision, colors of opaque objects, concave and convex lenses, the law of reflection. Individual knowledge advancement was assessed based on content analysis of student portfolio notes written in the three months, respectively (Table 1). Repeated measures ANOVAs revealed significant growth across the three months in the number of focal issues/goals addressed (F (2, 42) = 43.03, $p < .001$, partial $\eta^2 = .67$), epistemic complexity (F (2, 42) = 69.20, $p < .001$, partial $\eta^2 = .77$), and scientific sophistication (F (2, 42) = 70.60, $p < .001$, partial $\eta^2 = .77$).

Table 1: Student knowledge advancement measured based on their portfolio notes.

	1st Month	2nd Month	3rd Month
# of focal issues addressed so far	4.27 (1.83)	6.41 (2.02)	7.36 (.95)
scientific sophistication (1- pre-scientific to 4 - scientific)	1.48 (.66)	2.25 (.74)	2.81 (.48)
complexity (1-unelaborated fact to 4-elaborated explanation)	1.32 (.64)	2.04 (.78)	2.91 (.70)

Note. Numbers are means and standard deviations.

Community Dynamics and the Role of the Teacher

We analyzed the video transcriptions, teacher reflection, and student online discourse to understand how the productive knowledge building was achieved. A specific focus was on identifying significant moments of progress and then tracing backward and forward across activity contexts to understand how the process came about and where it further went. For example, a whole class conversation was conducted on May 16 that led progress in understanding how light interacts with opaque materials. The conversation began with students sitting in a circle and sharing observations of different materials. The teacher then highlighted a question originally raised by a student in Knowledge Forum: "Are all opaque things reflective like mirrors? " The following shows the first four of the 30 minutes or so discussion to address this and related problems.

Table 2: A Section of the Transcriptions of the May 16 Whole Class Conversation.

Transcription	Analysis highlight
2:20 GM: Well, there'[re] bricks, which are still opaque. But they're not reflective. But I don't know what they are called, like that kind of opaque. JL	Identifying non-reflective opaque materials, using a tentative voice.
2:31 JL: I think all opaque materials are reflective, except not all of them reflect light back. … OK, let's just say um like…a yellow carpet… your eyes would be able to see the yellow of it because it would only reflect yellow light. That means like that sort of like a tissue for example that would only reflect white, except the yellow carpet, since it's like green mixed with red, I believe. Then the beam of red [and green] light would touch us and your eyes would take it in as yellow.	Contributing an alternative idea: All opaque materials are reflective, by analyzing a thought experiment (yellow carpet), drawing on knowledge of primary and secondary colors.
3:58 Teacher: So you're saying everything is reflective then. Every opaque object is reflective to some degree. Oh, I hear some people disagree. Can you pass it on? [JL: SG.]	Revoicing student idea; highlighting contrasting perspectives.
4:07 SG: What about wood? Wood isn't reflective. JL.	Bringing in an anomaly.
…	
4:53 FJ: I think if wood is shiny and polished, you could see your reflection. I think it's mostly just shiny objects so it depends on what kind of wood you have, what kind of table you have, if you see your reflection. SG.	Re-analyzing and interpreting the instance as non-anomalous.
5:12 SG: Like if you had a glass table.	Supporting fact.
5:16 Teacher: The question is: Are all opaque objects reflective? Have we answered that? … Do all opaque objects reflect light? Anyone has a theory or evidence to support that? So, SG, it's yours to pass. [SG: DN.]	Highlighting/reminding a focal problem and promoting reflection on progress.
5:35 DN: Um, actually all opaque objects do reflect light, because they reflect their own color. So we see them as whatever color they are. TS. [inaudible student talking]	Articulating an idea and its supporting thoughts.
5:57 Teacher: Hold on, let's hear him talk.	Maintaining conversation norms.
5:59 TS: If they didn't reflect their own color, you wouldn't see a brick of red, or someone's t-shirt as purple or whatever. RP.	Extending and elaborating idea.
6:11 RP: What about black?	Bringing in an anomaly.
6:14 Teacher: Don't throw it back to him. Give your theory.	Maintaining norms; encourage initial thoughts.
6:18 RP: I don't think black reflects. I think that black might reflect light, but it might not. Because we had a reading today that um all the colors of the rainbow make white light and there is a note in the database about that, and everything reflects its own color. But it didn't say anything about black. EY.	Summarizing a reading and an online note and identifying black as an unaddressed issue.

A number of important ideas emerged from the conversation (e.g., all opaque things are reflective, expect black ones). Tracing each of these ideas back into the prior inquiry activities revealed striking historical connections and incremental moves. For example, the idea that all opaque things are reflective is rooted in a small group reading and related experiments on transparent, translucent, and opaque materials conducted on May 9; the notion that opaque objects reflect light of their own colors traced back to May 12 when group readings and discussions occurred focusing on how people see colored objects. These ideas were circled back into the current conversation leading to new inferences, connections, and meanings and further informing deeper problems and ideas.

Analyzing community interactions with each episode, such as the one shown above, and searching for cross-episode connections helped to identify essential processes/patterns enabling collaborative productivity in the community. Four thematic processes emerged, in consistence with the self-organization mechanisms sustaining knowledge creation synthesized in the beginning of this paper.

Process 1: Accumulating a Highly Variable Stock of Information and Ideas and Mobilizing Information Flow and Connection

Sub-process 1a: Accumulating a communal knowledge base that involves a richly connected history of ideas, with new inquiries evolving out of the old. The students accumulated a communal knowledge base—supported by Knowledge Forum—that helped to enable historical continuity between the old, current, and future work. Rich information flow took place on the basis of the community's knowledge base. Specifically, the students shared their understanding and challenges so as to construct a common ground while shaping emergent ideas and goals. Old ideas, problems, and inquiry works were constantly referred to and circled back to advance the current inquiry and discourse and further inform emergent goals (e.g., "going back to what X said about… , so…"). There was rich cross-referencing between the online and offline spaces and between different inquiry activities, as illustrated through the May 16 conversation analyzed above.

The teacher modeled making connections across ideas and activities and attempted to anchor all his major input in student history of inquiry. Specifically, he worked with the students to formulate emerging inquiry focuses/themes in the contexts of student prior inquiry and current interesting events. He helped to ground classroom conversations in relation to students' accumulated work and ideas, and highlighted connections between current inquiry and prior readings, experiments, and discussions. He also facilitated the online-offline connections, with important ideas and related inquiry work recorded in Knowledge Forum for further discussion and inquiry (e.g. "Is anyone writing a note about this experiment?"). When multiple small groups were conducting different investigations in the classroom, the teacher was often called upon by the students, who wanted to share with him their wonderments and excitements. He captured important progress of understanding and then catalyzed community wide discussion, online and offline.

Sub-process 1b: Making constructive use of information from reading. Efforts to accumulate a vibrant knowledge base were advanced through student constructive use of reading. To address important problems emerged from their inquiry, the students found and read a large amount of material. They worked in groups to understand difficult text, using reading strategies (e.g., questioning, reviewing, summarizing) to deepen their comprehension and discussion. Reading professional text and bringing important concepts and information to the community discourse helped the students to expand the knowledge base they could work with and appropriate sophisticated language to represent and process their ideas. It further engaged the students in reflective dialogues between their local understanding and knowledge out in the world (e.g., science communities). Consistent findings from the readings were synthesized and used by the students to support and extend their ideas. Inconsistencies were identified leading to further idea development.

The teacher modeled monitoring knowledge gaps in the community's knowledge space and introduced new readings by talking about existing questions and related ideas. As the inquiry went deep into the domain, many of the students-generated problems required readings above their current grade level. The teacher communicated his deep trust and high expectation and inspired students to collaboratively deal with difficult text for deep understanding. He consulted student interest in the readings to set up reading groups. Occasionally, he participated in the small groups to co-analyze and reflect on key information from readings, design related experiments, model various reading strategies. Across the inquiry activities, he helped the students to see connections between the current work and what they had read.

Process 2: Sustained Idea Development, Powered by Positive Feedback Loops

Sub-process 2a: The more we know, the more we can learn and generate: incremental idea development. The students connected to and made use of their shared knowledge base and peers' intellectual input to generate new ideas and deepen understanding. In the online and offline discourse (e.g., Table 2), the students made connections to and drew upon existing ideas and inquiry work to generate new ideas to address the focal problems. They often contributed ideas in the form of tentative conditional statements (e.g., maybe…) open to critics and further input (Engestrom, 2008). Their peers then responded to extend and elaborate these ideas; to contribute related thought experiments (e.g., what will happen if…), analogies (e.g., between eye and camera), observations, and supporting facts; to present alternative ideas and anomalies; to identify subordinate questions and distill challenges; and to summarize different perspectives for deeper conceptualizations. These interactive moves are characteristic of distributed reasoning observed in productive research teams (Dunbar, 1997), with existing ideas and knowledge operations constantly taken up by peers to enable further advancement.

The teacher nurtured among his students a sense of epistemic agency and empowerment. He communicated his deep trust that everyone had something worth saying and could contribute to knowledge advancement. In classroom conversations, he (a) engaged in active listening to and reading of student ideas; (b) expressed encouragement, interest, and excitement; (c) asked questions on student ideas for clarification and deeper thinking; (d) highlighted interesting ideas (including misconceptions) and questions, along with possible connections, controversies, and gaps; and (e) re-voiced student ideas (see Table 2) to make them more explicit and formal in light of related domain concepts (Hmelo-Silver & Barrows, 2008; O'Connor & Michaels, 1992).

Sub-process 2b: The more we know, the more we realize that we do not know, driving us to know more: Progressively identifying problems and formulating deeper goals. The students actively monitored and distilled challenging questions emerging from their discussions, reading, and experiments. Integral to their classroom conversations, they participated in meta-discourse to identify emergent questions and review conceptual connections among the questions so as to evolve interconnected deeper goals. For example in the May 16 conversation, the students identified questions such as: Does light reflect off of black opaque objects? How comes a mirror reflect light of all colors? Identifying these issues led to further idea development in the subsequent discourse, which then brought further problems of understanding to the fore.

The teacher explicitly encouraged students to take on high-level responsibilities and knowledge operations for sustained deepening of understanding. He encouraged students to ask 'why, why,' and not to be content with a superficial answer. He built on student discussions of emergent questions to propose his framing of focal inquiry goals, which was then discussed by the community. He engaged in deep listening to and reading of student ideas and questions, highlighted important problems emerged from classroom conversations, and asked questions to deepen student-generated ideas instead of directing the students to new tasks (Zhang et al., 2009). He also reminded/brought back problems that had not been addressed and requested reflective review of progress (e.g., "Could someone summarize what we've come to so far at this talk?"). The students oftentimes did the same supported by the teacher's modeling.

Process 3: Critical Examination and Selection of Ideas, as Negative Loops

Sub-process 3a: Individual reflection and critical idea examination in the discourse. Individual reflection appeared to function as a bottom-level mechanism of idea examination and selection to make sure that everyone contributed clearly presented and carefully reasoned out ideas addressing communal goals. When presenting information and ideas, the students acknowledged the sources and connections to prior work of peers. They used conditional statements and indicated both what they knew and what they were not sure about, in reflection of the "half-baked" nature of their ideas. Student idea input was further examined and selected through critical dialogues. In the dialogues (e.g., Table 2), the students challenged peer ideas by presenting alternative explanations, identified and analyzed anomalies, and raised questions that challenged existing explanations. The competing explanations, possible anomalies, and challenging questions *per se* then became objects of critical discourse. The examination of two competing explanations might lead to giving up one of them; but in many other cases, it led to rising above different perspectives towards more complicated explanations.

Related to idea examination and selection, the teacher was cautious not to be the judge of student ideas. But rather, he highlighted rules of reflective contributions (e.g., contribute ideas with details) and engaged his students in meta-discourse to review ideas, monitor gaps, conflicts, and challenges, and reflect on progress, using identified contrasting perspectives to stimulate deeper examination and analysis.

Sub-process 3b: Empirical testing of ideas. Focusing on important questions and ideas about light, the students designed and conducted experiments and observations, often in small groups. The students collaboratively identified focal problems and deeper questions to be addressed, generated theories, designed experiments, interpreted findings, and discussed new insights. They brought their new understanding and supporting evidence to the subsequent discourse for broad sharing, collective scrutiny, and further build-on. Their experiments were emergent and idea-centered instead of as pre-scripted tasks, with the goal of collecting data to examine and develop explanations.

The teacher listened to and read student ideas and suggested the need of evidence to examine different ideas, such as by saying: "I'm interested in your theory. Can you design an experiment to test this idea?" He listened to student proposals for experiments and promoted reflective thinking, such as by asking: "What are the questions you are trying to answer?" "What are the steps you will go through?" Based on the students' proposals, the teacher helped them to find needed materials and instruments.

Process 4: Distributed Emergent Control

Sub-process 4a: Co-constructing principles, strategies, and support structures. In all types of inquiry work, the students reflected on and talked about how things should be done, and why, leading to deep understanding of what it means to work as a knowledge building community. They talked about collective ownership over inquiry questions and ideas, so that a community member might read and find information that was beyond his/her immediate personal focus. They talked about norms of knowledge building discourse, such as active listening/reading, contributing ideas in full paragraphs with evidence and details, and making connected and non-redundant input (e.g., do not write a note that simply repeats a question or idea). The community members also co-developed and utilized a variety of externalized structures to guide, assist, and deepen knowledge building. For example, to represent knowledge goals and guide their writing of reflective portfolio notes, the students collectively generated a list of thematic questions (e.g., how mirrors work) in line with their focal goals and then turned the questions into a set of new scaffold labels in Knowledge Forum. To assist experimental design and reporting, the teacher and his students discussed and agreed on key elements of a scientific experiment (e.g., theory, steps, results). The elements were then listed by each student in the front page of his/her laboratory notebook.

In the classroom discourse/meta-discourse, the teacher discussed, modeled, and reminded students of the basic conversation norms and rules, which encouraged collective engagement, reflective thinking, and sustained improvement of ideas. He shared with the students his classroom design ideas open to their input.

Sub-process 4b: Collective responsibility, adaptive roles, and opportunistic planning. The students monitored progress of understanding, identified challenging issues to be addressed, and synthesized important knowledge advances in each Knowledge Forum view. They brought the advances and challenges to whole-class conversations to look into possible deep connections and formulate further inquiry goals. Individuals then decided which aspects of the inquiry goals they wanted to contribute to and in what ways (e.g., theorizing, experimenting, reading), with those who had shared interest often forming into temporary small groups. The community awareness of who was working on what further created a social pressure that helped to increase individual accountability (Zhang et al., 2009). Sometimes, student peers would ask a student/group: "You have been working on this for a long time. You need to tell us what you have found."

The teacher's classroom design was characteristic of opportunistic planning (Sawyer, 2007). He identified related "big ideas" in the domain and thought about how the ideas might be approached in light of his understanding of knowledge building principles (Scardamalia, 2002) and observations of previous classes. Doing so helped him to create a big picture in mind about how the inquiry might evolve while leaving all detailed processes open and co-improvised with his students (Zhang et al., 2009). He actively observed student work and listened to their ideas to understand their progress and challenges; contributed to meta-discourse to formulate, distill, and highlight knowledge goals; created, linked, and adjusted view structures in Knowledge Forum in line with the evolving goals; listened to student inquiry plans and gave suggestions; and walked between small groups to understand their progress and offer on-site advising. Sometimes, he also proposed action plans. When doing so, he always connected his proposals to existing ideas, questions, and input from the students, such as by saying "I'm interested what X said earlier about…"

Discussion

The content analysis of the students' online discourse and portfolio notes revealed high-level collaborative productivity achieved by the community. The qualitative analyses of the classroom videos and teacher reflections further elaborated four interrelated processes that sustained the collaborative productivity, with the teacher's roles identified in each of the processes.

Efforts to engage students in distributed, opportunistic collaboration for knowledge building often face the questioning of how students possibly know what to do to make productive progress. Such questioning is rooted in a common belief that students need a "strong leader" to chart and organize the process of knowledge building and tell them what tasks/sub-tasks to be done and in which ways (e.g., using scripts). This study elaborated collaborative productivity as emergent, self-organizing processes. Neither the teacher nor the students knew beforehand how the inquiry would exactly unfold. The course of inquiry and collaboration and the key moments of progress emerged from an interactional process in which the teacher and his students co-contributed to the unfolding classroom flow. Student interactions augmented through the shared knowledge space in Knowledge Forum enabled continuous and incremental idea development. They identified important and relevant ideas from the past as the stepping-stones of their new inquiry, triggering deeper ideas and problems. Each major idea was embedded in the evolving intellectual history of the community, gaining support from the past work and further informing and enabling future idea development (Tabak, 2004). As a result, new deepening goals and plans emerged as the inquiry history unfolded. Instead of having the teacher make high-level decisions regarding the rules, structures, goals, and procedures, the community members took on collective responsibility for evolving goals and developing productive practices and structures.

The significant advances in the community's knowledge did not come about through sudden insights that departed from existing knowledge, but through historical build-on, incremental refinement, and accumulative selection of ideas (Cziko, 1995; Dunbar, 1997; Sawyer, 2007). Student ideas and questions were constantly taken up by peers and used as the input to further operations of knowledge, leading to idea generation, elaboration, diversification, and improvement. The advanced understanding further helped to inform deeper problems at the frontier, enabling sustained cycles of progressive problem solving. Thus, the more they knew, the more they could generate; and the more they realized that they needed to know. These positive loops fueling sustained idea generation were coupled with critical idea examination and selection. In the knowledge building discourse, ideas were often contributed in a tentative voice open to critics and further input; competing explanations, possible anomalies, and challenging questions were raised calling for further examination of ideas; empirical evidence was collected and brought to discussions.

Elaborating the self-organization mechanisms underpinning collaborative productivity sheds light on various aspects of community scaffolding—the community as the provider as well as recipient of scaffolding—through emergent, distributed processes (Davis & Miyake, 2004; Tabak, 2004). Members use their historically accumulated ideas to support the current work and inform deepening goals; New ideas and inquiry strategies are objectified and selectively retained to enabled further advances; Collaborative discourse among the members enables sustained chains of distributed reasoning (Dunbar, 1997); Supportive principles, rules, and external scaffolding structures are developed, monitored, and adapted through reflective discourse. The roles of the teacher aligned with each of the processes exemplify specific teaching designs and strategies to nurture and support knowledge building. Viewing these specific roles and strategies through the lens of self-organization helps to understand how these roles synergize with one another (Tabak, 2004) and how teacher scaffolding leverages community scaffolding for productive knowledge building.

Future work needs to further examine the self-organization mechanisms that sustain collaborative knowledge building in different grade levels and explore if some of the processes (e.g., positive and negative loops) can be used as leverage points to help transform classrooms into creative communities.

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