Sustaining Principle-Based Knowledge Building Innovation at an Elementary School

Jianwei Zhang, Marlene Scardamalia
Institute for Knowledge Innovation and Technology
OISE, University of Toronto

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Email correspondence: zhangjw@kf.oise.utoronto.ca.

Abstract

Sustainable knowledge building requires working with emergent rather than fixed goal structures, and opportunism in knowledge work rather than fixed routines. Thus the pedagogical model requires teacher innovation, surrounding a principled rather than procedural approach to teaching. Using social network analysis and other quantitative methods, this study analyzes students' online discourse in 34 knowledge building initiatives facilitated by nine teachers at an elementary school over seven years. The results demonstrate significant advances of knowledge building practice among the teachers. Improvement was reflected in increasing individual contributions to collective knowledge resources and taking collective responsibility for knowledge advancement. These results suggest the feasibility of school-wide, principle-based knowledge building innovation. Qualitative analyses of the teachers' reflection journals and interview data revealed several key aspects of their efforts for sustaining principle-based knowledge building innovation.

Introduction

Dozens of inquiry-based learning programs have emerged in response to the need to develop students who can work productively with knowledge (e.g., Brown & Campione, 1990; CTGV, 1996; Edelson, Gordin, & Pea, 1999; Hmelo & Lin, 2000; Krajcik, Blumenfeld, Marx, Bass, & Fredricks, 1998). Scaling up innovations of this sort represents a major challenge: the most difficult part is the enactment of first principles underlying the innovation. Without adherence to first principles, learning innovations are to be ritualized and

degraded as a set of surface procedures (Brown & Campione, 1996). As Coburn (2003) pointed out, to be "at scale," reforms require deep and lasting change—change beyond surface structures or procedures. In this process, the role of practitioners is not to simply implement an "external" reform, but to develop ownership over the reform and "capacity to sustain, spread, and deepen reform principles themselves." (p. 7)

Despite the recognition of the importance of principle-based innovations, implementation of learning innovations generally relies on an approach that turns a learning program into an activity package focusing on certain curriculum topics, supplemented with technological resources, assessments, and teacher's guide (e.g., Penuel & Means, 2004). A current, typical form of a curriculum activity package is a pre-designed inquiry project, which involves a specified culminating task, and a fixed stage-model of inquiry with a set of procedures for information collection, analysis, integration, and presentation. Teachers are expected to implement the scripted processes in their classes with high fidelity, or at a deeper level, to play a role of local adaptors of a designed curriculum to ensure a strong fit with local circumstances (Barab & Luehmann, 2003). Such an approach echoes Black and William's (1998) concern that teachers will not take up new ideas "if the ideas are presented as general principles that leave the task of translating them into everyday practice entirely up to the teachers."

Knowledge building represents a principle-based innovation with the goal of enculturating students into knowledge building communities where students' ideas have a public life, being continually revisited, critically examined, applied, revised, re-organized, and risen above (Scardamalia & Bereiter, 1994, 2006). This collective process is advanced through Knowledge Forum®, a computer-based knowledge building environment (Scardamalia, 2004). Knowledge building practice in classroom is guided by a set of 12 principles: *real ideas, authentic problems; improvable ideas; epistemic agency; collective responsibility for community knowledge; knowledge building discourse; constructive use of authoritative sources; democratic knowledge; idea diversity; rise above; symmetric knowledge advances; pervasive knowledge building; and embedded, transformative assessment* (Scardamalia, 2002). Authentic knowledge-creating practices emerge from a social process that engages participants in complex, unpredictable interactions (Sawyer, 2003), with goals emerging from interactions within a complex network of people and ideas (Valsiner & Veer, 2000). Sustainable knowledge building requires working with emergent rather than fixed goal structures, and opportunism in knowledge work rather than fixed routines (Zhang, Scardamalia, Reeve, & Messina, 2006). Thus the pedagogical model requires teacher

innovation, surrounding a principled rather than procedural approach to teaching. The role of teachers is not simply "implementer" or "local adaptor" of a set of knowledge building curricular or activities, as there are no activity packages provided. More essentially, they function as "pedagogical knowledge builders," deepening their understanding of knowledge advancement in light of knowledge building principles, inventing and improving processes and structures to bring knowledge building to classroom life, and helping to advance their profession. Teachers, like their students, take on high-level responsibilities in knowledge building practice, committed to collective and continual idea improvement, through which they identify and solve progressive problems and continually go beyond best practice (Bereiter, 2002). For example, to foster students' collective responsibility for knowledge advancement, a Grade 4 teacher improved his designs over three years, starting with a specialized small-group design, evolving to an interacting-groups design, and eventually to a more flexible structure that encourages distributed, opportunistic collaboration, leading to increasingly higher levels of collective responsibility and knowledge advances (Zhang et al., 2006).

Can teachers in a school effectively enact principle-based knowledge building innovation and continually improve their practice? What kinds of efforts do teachers need to make in order to sustain this principle-based innovation? The present study addresses these questions by testing and looking into teachers' knowledge building practice in an elementary school.

Method

The Teachers and Their Knowledge Building Practices

This study examined the knowledge building practice of nine teachers working with Grade 2 to 5/6 students (22 students in each class1) at the Institute of Child Study (ICS) of the University of Toronto. Their work constitutes the school-wide knowledge building innovation, the essence of which is giving students collective responsibility for idea improvement. During the past seven years, the teachers implemented a large number of knowledge building initiatives with the support of Knowledge Forum. Each initiative investigates a core curriculum area over a continuous period, for example weather, environment, plants, worms, light, sound, human body, earth, astronomy, electricity, communities, North American history, Medieval culture, ancient civilizations, traditions, and so forth. For this study we selected 34 initiatives spanning at least four weeks each. Table 1 shows the number of knowledge building initiatives facilitated by teachers with

[1] Several students who had not granted permissions for this research were excluded from our analysis.

different years of knowledge building experience among students of different grades. It should be noted that knowledge building pedagogy and technology has been used in Grade 1 and Junior and Senior Kindergarten in this school, but results from these early grades are not reported here. Knowledge building in those classes was not included in the analyses.

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Insert Table 1 about here

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Data Source and Analyses

Each knowledge building initiative integrates knowledge building work in classroom with online discourse in Knowledge Forum. Students record their advances generated from their classroom work (e.g., discussions of problems and theories, experimental findings, and information from readings) into Knowledge Forum for sustained conversations. Student discourse in Knowledge Forum provided the basic data source for us to examine the knowledge building practices enabled by the teachers. Using analytic tools underlying Knowledge Forum, we analyzed students' behaviors including note creation, problem statements in notes, note reading, and note linking through build-ons, rise-aboves, and referencing citations. Particularly, we applied social network analysis (SNA) (Scott, 1991) to look at two types of social interactions in a community: who read whose notes and who linked to whose notes. The note reading and note linking relationships in each knowledge building initiative were represented as case-by-case (member-by-member) matrices, with values indicating the frequencies of interactions between each pair of participants. We used two basic measures to look at students' note reading and linking in a network. (a) Inclusiveness: In a social network, members/actors are shown as nodes, and connections between nodes are represented by lines. Inclusiveness is the percentage of non-isolated nodes in a social network. A collectively engaged knowledge building community should have a high inclusiveness in terms of note reading and linking interactions. (b) Density: Density of a network is reflected in the number of lines divided by the maximum number of all possible lines (Scott, 1991), with a value varying between 0 and 1. In a high performing knowledge building community, members should learn about and build onto the inquiries, resulting in dense note reading and note linking networks.

The above analyses measured students' efforts for collective knowledge building along three dimensions (Zhang et al., 2006): (a) Individual contributions in a community knowledge space; (b) Awareness of contributions made by other members; and (c) Complementary contributions as indicated by efforts to build on other's contributions,

connect to others' work, and rise above diverse ideas to advance community knowledge. Table 2 summarizes the specific measures in line with the three dimensions, which are elaborated below. Due to the large number of inquiry initiatives analyzed, this study did not include in-depth analysis of the content of students' discourse. Fortunately several other studies have already made focused, content analyses of students' knowledge building discourse (e.g., Chan, Lam, & Leung, 2007; Hakkarainen, 2003), with significant correlations found between quantitative behavioral measures such as note reading, note contribution, and building on and content analyses of knowledge advances (Zhang, 2004; Zhang, Scardamalia, Lamon, Messina, & Reeve, in press).

Insert Table 2 about here

Additionally, we used qualitative methods to understand how the teachers enact principle-based knowledge building innovation and improve their practice over the years. The data sources included: (a) Teachers' reflection journals called "Calendar of Inquiry (COI)," in which teachers recorded their knowledge building designs, classroom processes, and reflections on advances and problems; and (b) Interviews with two teachers, one with six, and the other with three years of experience with knowledge building pedagogy and technology. Each interview took approximately 40 minutes, focusing on progress in teaching practice. Following the process of inductive data analysis (Hatch, 2002; Strauss & Corbin, 1998), the first author read and re-read the above data and identified salient domains—major aspects of teachers' efforts to sustain principle-based knowledge building innovation. Each salient domain was represented by identifying "included terms" (members of a category) and their "cover term," followed by a search for connections across the domains.

Results

An Overview of the Knowledge Building Initiatives

On average, each knowledge building initiative lasted 150.93 days (SD = 101.37) from the first to the last note creation in Knowledge Forum that was entered into a view specifically related to the theme under investigation. As a stricter measure of time investment in an initiative, we counted the number of "Knowledge Forum-active days", each of which had at least one new note contribution. Each initiative had an average number of 29.24 (SD = 18.22) Knowledge Forum-active days. The initiatives emerged from students' interests and addressed disciplinary themes, so one knowledge building initiative

was frequently related to another.

Individual Contributions

As a measure of students' contributions in a community knowledge space, we analyzed the number of notes created by each student in each initiative (see Figure 1). This number is between 5 and twenty for most of the initiatives. An analysis of variance (ANOVA) was run using students' grade levels (lower vs. upper grade) and teachers' knowledge building experience (1 year, 2 years, 3 or more years) as between-group factors and Knowledge Forum-active days of the initiatives as a covariate. Significant effects were found for teachers' knowledge building experience ($\underline{F}$ (2, 700) = 27.14, $\underline{p} < .001$, $\underline{\eta}^2 = .07$), students' grades (F (1,700) = 8.37, $p < .01$, $\underline{\eta}^2 = .01$), as well as the number of Knowledge Forum-active days ($\underline{F}$ (1, 700) = 525.19, $\underline{p} < .001$, $\underline{\eta}^2 = .43$). As they proceeded with the knowledge building pedagogy, the teachers could engage students more actively in sustained knowledge building discourse. Interestingly, students in Grade 2 and 3 were able to create even more notes than those in upper grades, although a word count indicated that their notes were overall much shorter than those written by older students.

Insert Figure 1 about here

A feature of Knowledge Forum encourages students to indicate the focal problem to address in a note. The analysis of students' problem statements in notes provided information about the conceptual focus of notes. An ANOVA indicated that teachers' experience with knowledge building had a significant main effect on the number of problems worked on per student in a knowledge building initiative (F (2, 700) = 30.64, p < .001, η^2 = .08), interacting with students' grade levels (F (2, 700) = 3.84, p < .05, η^2 = .01). In initiatives facilitated by more experienced teachers, each student tended to work on multiple focal problems. This trend is stronger among students of upper grades.

Insert Figure 2 about here

Community Awareness

In Knowledge Forum, students get acquainted with each other's problems and ideas by reading each other's notes. We applied SNA to the log data of who read whose notes, and computed the density of note reading contacts in each initiative, which indicates to what extent every possible pair of students had read each other's notes. As Figure 3 indicates, the average density of note reading was quite high, with most knowledge building initiatives having a density higher than 0.65. There was a trend of growth in the density of note reading associated with teachers' knowledge building experience, although not statistically significant (p > .10) possibly due to a ceiling effect.

Insert Figure 3 about here

Complementary Contributions

To examine students' collaborative efforts for knowledge advances, we analyzed the social network of note linking contacts (i.e., building on, rising above, and referencing) in each knowledge building initiative. The overall inclusiveness of the networks was quite high, with around 80% students engaged in sending out and receiving note-linking contacts. As Figure 4 shows, the densities of the note-linking networks varied considerably. An ANOVA demonstrated significant effects for teacher experience (F (2, 26) = 4.93, p < .05, η^2 = .28) and the number of Knowledge Forum-active days (F (1, 26) = 39.97, p < .001, η^2 = .61),

with a marginal effect observed for students' grades (F (1, 26) = 3.95, p = .057, η^2 = .13). There was a consistent growth in the density of note linking contacts associated with teachers' experience. Grade 2 and 3 students outperformed their older counterparts in pursuing interactive knowledge building discourse.

Insert Figure 4 about here

Understanding the Process of Principle-Based Knowledge Building Innovation

The above analyses demonstrate that the teachers were able to create a social structure conducive to knowledge building among students at different grade levels (3 to 6) and improve their practice year by year. The qualitative analyses of teachers' reflection journals and interview data help uncover processes relevant to principle-based innovation. Major categories that emerged from the data include:

(a) Deepening Pedagogical Understanding and Evolving Designs. The teachers started their knowledge building practice with understanding the knowledge building principles, as described in writing materials and presented by researchers and teachers. There are no standard "how to" procedures provided to teachers regarding the implementation of the principles. Classroom practices and effective knowledge building depend on teacher innovativeness and the formation of a knowledge building community among teachers in which classroom activities, knowledge building principles, challenges and possibilities are discussed at weekly professional development meetings, with the goal of exchanging insights and continually advancing best practice. Data analyses indicated that the teachers invented and tested a wide range of design strategies. They often focused on one or two of the 12 knowledge building principles in a particular year, trying to achieve a deeper understanding of the principles as they test and reflect on specific designs. For example, one of the knowledge building principles is "knowledge building discourse," which refers to discursive practice that results in not only the sharing of knowledge, but also the refinement and transformation of knowledge and emergence of new ideas (Scardamalia, 2002; Scardamalia & Bereiter, 2006). Knowledge Forum supports knowledge building discourse in an online environment that is a continuation and enrichment of classroom conversations. To engage students in knowledge building discourse in classroom, teachers at the school of the present study developed a design called "Knowledge Building Talk" ("KB Talk"). The original design of a Knowledge Building Talk is to have students sit in a circle, with the teacher as an equal member of the group. Their conversations focus on problems of understanding and knowledge advances, with the goal of collectively seeking deeper understanding in a domain (see Reeve, 2001). This approach has been subsequently adopted by many teachers in the school. Data Analyses show that the teachers do not merely

replicate the activity structures of their peers, but have evolved different design strategies to engage knowledge building discourse in different classroom contexts. Below are two teachers' reflections on their improvements to Knowledge Building Talk:

> We would hear what the principle was, [knowledge building discourse]. We would go into the classrooms, and we would do it DIFFERENTLY. And then we would come back and talk about it… When I first started, KB talk was on the schedule. They were every Tuesday 10 o'clock. I realized that wasn't working, because sometimes we had that time and we had nothing to talk about. Then we developed a sort of... We have pockets on the board, and if you have something to talk about, you would write it on a piece of paper…They would put the paper there, and I would pull them out, read it out, or pass it to that person. That was better, but still a bit too prescriptive. What's happening now… is I don't necessarily plan a KB talk. But they become more spontaneous. KB talks always used to be sitting down in a circle; that is not the case any more. It could be in the classroom, someone sits in the chair, someone sits on the floor, as long as everyone is following…Also that my role...I think I'm not a very quiet person in KB talk. When I interrupt, which I do, I'm a teacher saying: "Can you please say that a little bit more because the people on this side did not hear what you said." I'm more comfortable with that. You know, "Oh. I spoke again. That's terrible!" Now I realize no, I mean, we are still modeling for children… So that's my evolution of KB talk. Much less structured, more organic, spontaneous. They also can vary. I mean, we are not trying to filling up 30 minutes. If takes 10 minutes, that's it. If it takes 40 minutes, that's fine too. (An except from Teacher R's interview)

> I played around with it (KB Talk) a lot, because I'm really interested in discourse, and in trying to have children talk to each other without putting their hands up, so that if their ideas build on to someone else's, they can just say it. So I over the years was trying to get one person start and the children just talk. They take turns and don't put their hands up. They learn to hold back. If someone else starts to talk at the same time, they need to wait. It's very hard for kids, but I like the discussion that feels more like a conversation, not like the teacher choosing as the children put their hands up. So that's been a big thing for me. (An except from Teacher Z's interview)

Analysis of other teachers' reflection journals also indicated their improvements to Knowledge Building Talk. For example, in order to better integrate Knowledge Building

Talks with online discourse, Teacher P teaching Grade 2 experimented with a strategy of projecting their Knowledge Forum database on to a screen during a Knowledge Building Talk, turning students' online work into objects of face-to-face conversations. As has been observed in many contexts, teachers need to adapt and localize an innovation to meet the conditions and needs of their local contexts, ensuring a fit between the innovation and the local circumstances (Barab & Luehmann, 2003). Teachers in the present study also need to "adapt" Knowledge Building Talk and other designs to make them feasible in particular contexts (e.g., student age). But they are not merely seeking a "fit," but continually creating innovations to the designs based on their reflections upon the principles and classroom processes and new insights they gain from colleagues and researchers. They are responsible for the initiation of the designs, and maintain intentional efforts to experiment with new design features to enable more productive, authentic, and collectively engaged knowledge building processes.

(b) Identifying and Overcoming Barriers. The implementation of knowledge building principles faces different practical conditions and barriers in different classroom settings. Analyses of reflective journals and interview data revealed teachers' efforts to overcome barriers and constraints related to variables such as subject areas, student age, time, schedule, technology access, and so forth. For example, in her first year with the knowledge building pedagogy, Teacher Z worked with a Grade 2 class. According to her reflection journal, a challenge she encountered was that the second-graders were not comfortable typing, so they could not enter their ideas into Knowledge Forum's communal space so others could build on and improve them. After talking to her colleagues at a meeting, she decided to address this challenge using several strategies:

> Children who want to will type their notes themselves. When children are on the database, adults (the teacher and her intern) may come and offer to take over the typing for a period of time or to help them to finish off their note if time is running out or if the child seems to be tiring. Children may request that an adult type the entire note for them. Children may write the note by hand and have an adult enter it into the database as the child reads it aloud.

After testing these strategies in her classroom, the teacher wrote:

> I think that giving them choices … does provide a way in for everyone and that not insisting that they type for themselves takes typing out the equation and puts ideas at the centre.

In another example, Teacher B teaching Grade 5/6 classes experimented with strategies to implement knowledge building in math, which is often considered more fact- and procedure-focused and less favorable to knowledge building pedagogy. After she facilitated a Knowledge Building Talk about the application of percent in daily life, she wrote in her reflection journal:

> What a rich discussion the children held. That's definitely the richest discussion I've ever heard in a math class that I've run! It is quite amazing to hear the quality and depth of thought that the students are capable of. It makes me think that I wouldn't have known what was in the minds of the students had these questions not been asked of them - we're often so busy making sure they can work out the problems in the textbook, finish up the page, etc. that we don't give time to discuss ideas. Who would have thought that you could have a sustained whole class discussion around math?

(c) Collaborative Emergence. Working with a set of principles instead of pre-specified procedures, the teachers perceived great opportunities and demands to make flexible, responsive decisions during classroom interactions, with planned activities adjusted and new strategies generated and adopted in an emergent way. This is challenging for teachers, as they need to re-conceptualize their role and control in classroom. The teachers in this study seemed to have gradually embraced greater emergence and opportunism in their approach as their comfort level increased. For example, responding to the interview question about major advances he had made in teaching in the past years, Teacher R reflected:

> The other thing … is the control that as a teacher, when you're early in your career, you want…the principal to come to your room, and you're able to say: "Everybody is writing that right now." You know, that's safe. Knowledge building is not like that. So in order to feel like I knew what everybody is doing … I spent a lot of time saying: What you're going to be doing, what you're going to be doing, OK, go, come back, tell me what you did. I still do a little bit of that. But it took a lot of time to do that, and was still very structured, and there wasn't enough fluidity. So I learned to really have to face what students do. … So the students thought they were reading an article about something, then new question appeared. They could actually go and do something else. So as a teacher I have to learn that it's OK to say: "I'm not sure what that group is doing." I can go and find out and ask them. I know that they were able to answer it. The children might work inside, outside, in the hallway. That's fine, because when they come back, I realize students are usually on task, and they are able to go deeply,

because they have been given the opportunity to do that.

Teacher R's evolution towards more emergent, fluid classroom processes is also reflected in his approach to Knowledge Building Talks as elaborated above. A related interesting phenomenon observed in this as well as other teachers' data is that classroom designs are often co-constructed by teachers and students through an interactive process. Students and their teacher collaboratively decide on what views should be created in Knowledge Forum, how they should be linked, and how students should be grouped. They discuss issues such as: what are the weak areas that need deeper research? what experiments need to be conducted to test our theories? when do we need a Knowledge Building Talk and what should it focus on?, and so forth. These classroom processes are characteristic of what Sawyer (2004) terms "collaborative emergence:" The process cannot be predicted and pre-specified in advance; the outcome is collectively determined by all participants instead of a single, authoritative member. Collaborative emergence exists in many contexts, however teachers depend on collaborative emergence to enact principle-based innovations.

(d) Reflection on Key Issues in Light of Principles. Analyses of reflective journals and interview data revealed the teachers' consistent efforts to monitor and reflect on their classroom processes and designs in light of the knowledge building principles: Are students improving their ideas and deepening understanding of key content areas? Are there idea improvements evident in Knowledge Building Talks, or at least evidence of probing questions and desire to go deeper? Are they enacting collective responsibility for community knowledge? How can a teacher intervene in the knowledge building process without discouraging students' epistemic agency? For example, Teacher J working with a Grade 3 class wrote in her first year's reflection journal:

> The whole notion of a knowledge building community is something that … has to be made much more explicit. Our investigations have to have a clearer agreed upon direction. … Many students honed in on individual questions and connected only minimally to their classmates.

Identification of the above problems helped the teacher develop more effective designs. She recognized the need to incorporate whole class Knowledge Building Talks as early as possible to help define the goal of the community and increase students' collective responsibility. Critical reflections of this kind seem particularly important when unfavorable situations occur. Through reflections, teachers can figure out significant reasons behind the

problems and work out a plan to move the community onto a productive route. For example, Teacher R teaching Grade 5/6 once found that some of the Grade 5 students showed resistance to writing notes in Knowledge Form. Through his observation and reflection, he realized that a possible reason was that the students had been asked to use Knowledge Forum too much for things that are not necessary, for example to write down factual information they had found that involved little knowledge building work. This made them think of Knowledge Forum as an extra layer of labor. The use of Knowledge Forum has to be for the sake of solving authentic problems and improving students' ideas. The following except from his interview shows how he worked out of this situation:

> What helped me was that the Grade 6 students had a wonderful year using Knowledge Forum last year, studying human body. We used it for deep questions. … They loved it…So this year, the Grade 5s said: "How are we going to do this?" I really wait until it makes sense. Then students would say to me: "Can I put this on KF (Knowledge Forum)?" I would say: "No, no, that shouldn't go." They were surprised...Somebody they know who uses KF to build knowledge would say: "It was necessary only if you want to." That's the idea of choice. Then they were more open to the idea that it makes sense to use it now, because we would be studying a deep question that we can build on. What I found in this is that some of the students who just hated it at the beginning are the one saying: "Can I write a note about this in KF that we can build on?" So we have to really be careful of how we use the technology that is not for the sake of technology. It has to be for the sake of knowledge building. Some knowledge building happens in KB talks, some happens in notebooks, and some happens there (in Knowledge Forum).

Discussion

Associated with the scalability and sustainability of a learning innovation is a challenge to ensure the enactment of first principles underlying the innovation (Brown & Campione, 1996). Dealing with this challenge entails teachers' capacity to appropriate and deepen the principles themselves (Coburn, 2003). However, literature presents a general concern about whether teachers can take up new ideas presented as general principles and translate them into practice (Black & William, 1998). Knowledge building pedagogy and technology represents a principle-based innovation that requires teachers to continually re-invent and improve classroom processes in light of the knowledge building principles. By analyzing knowledge building initiatives facilitated by nine teachers at an elementary school,

this study demonstrated advances related to their knowledge building practice. The high inclusiveness of note reading and note linking interactions indicates that the teachers, even in their first year with knowledge building, were able to create knowledge building communities with a way in for all students. As the teachers proceeded, they were able to facilitate knowledge building communities with higher contribution rates, as indicated by the number of notes students created and problems they worked on; and increased complementary, collaborative efforts for building knowledge, as indicated by their building on, note referencing, and rising above behaviors in Knowledge Forum. As has been shown in earlier studies, these basic behavioral measures such as note creation and note linking are significant predictors to student knowledge advances in a knowledge building community (Zhang, 2004; Zhang et al., in press). Arguably, the improvements on these basic measures suggest the overall progresses of the teachers' knowledge building practice, although no content analyses have been made. The results provide evidence for the possibility of sustaining school-wide, principle-based knowledge building innovation, with teachers in the role of pedagogical knowledge builders who appropriate and deepen principles and create and improve classroom designs in light of them. Teachers can be innovators (Randi & Corno, 1997).

The qualitative analyses of the teachers' reflection journals and interview data revealed several aspects of their efforts for sustained principle-based knowledge building innovation. They intentionally seek deeper understanding of the knowledge building principles, and continually evolve flexible, effective designs to adapt to their classroom contexts and go beyond their best practice. They identify and overcome important barriers to knowledge building in their classrooms, bringing this pedagogy to new student groups, subject areas, and classroom conditions. They embrace collaborative emergence (Sawyer, 2004) in classroom, making flexible, responsive decisions and working with students to identify what they need to do as their work proceeds. They keep reflecting on what's happening in classroom and in Knowledge Forum, in light of core knowledge building principles, to see whether students are assuming greater levels of agency, making progress and, if anything is wrong, detecting and remedying problems. The above efforts contributed to the sustained improvement of their knowledge building practice, so that the teachers are all able to make progress despite the differences in their contexts.

All teachers refine their practice over time in some way. Natural growth—or mastering the craft of teaching—is often associated with stabilization of procedures and smoother performance (Bereiter, 2002). The above analyses suggest a transformative process of

improvement among teachers in knowledge building innovation. Instead of merely smoother and more ritualized skills, they intentionally advance their understanding about key issues in their profession (e.g., knowledge and its advancement, student potentials, curriculum), seek new challenges and problems, experiment with new ideas and designs, and generate new classroom organizations as emergents of the ongoing knowledge building processes. They are knowledge builders in their own right, in addition to engaging their students in knowledge building. As one of the teachers reflected: "I think that my understanding of the principles completely is different today than it was my first year, and even it is different than a year or two ago. … You're constantly going deeper in what this means... This is a process you need to go, and it never stops." This continual, transformative process of improvement is central to the nature of principle-based innovation that gives teachers high-level responsibilities in creating and evolving an innovation.

To understand key contextual factors conducive to continual advancement among the teachers, we are further analyzing their reflection journals, meeting records and interview data from more teachers. Primary analyses suggest that teachers themselves have formed a knowledge building community for shared, progressive problem solving (Hong, Zhang, Teo, & Scardamalia, 2006), which in many ways resembles what McLaughlin and Talbert (2001) called a "teacher learning community," focusing on collaborative pedagogical innovation. The school creates a safe and supportive environment where teachers are encouraged to expose their problems, seek deeper understanding of the knowledge building principles, experiment with new ideas and designs, and sustain collegial dialogue and critical reflection. On a regular basis, the teachers meet to talk about their problems and advances; and share their plans, actions, observations, reflection, and problems in Knowledge Forum, which is accessible to colleagues and researchers. Instead of trying to eliminate problems and ritualize their classroom practice, they accept problems and their emergence in new forms as a norm of their practice, with dedication to levels of productive disequilibrium (Wilson & Berne, 1999) that allow them to improve their practice each year.

In sum, this study demonstrated sustained improvement of knowledge building practice among the teachers. The results suggest the feasibility of sustaining school-wide, principle-based knowledge building innovation, with analyses of teachers' reflections and interviews helping to uncover key processes of principle-based innovation. This study helps inform next steps: to establish knowledge building schools in different school districts, to create a shared repertoire of "knowledge building objects" that represent teachers' strategies and inventions, and to establish partnership/mentorship between veteran and novice teachers

and schools.

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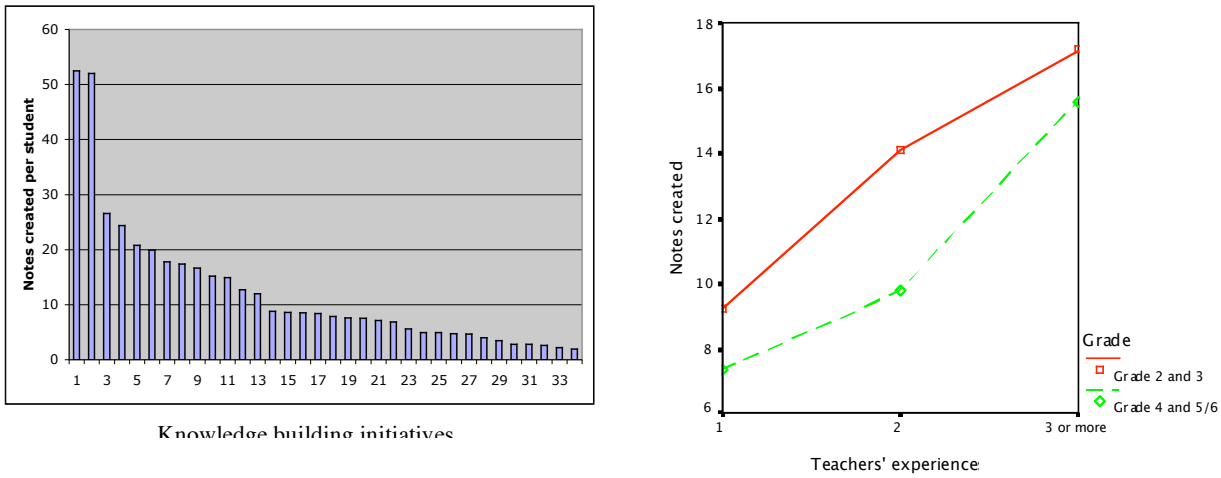

Figure 1. The average number of notes created by each student in each initiative, facilitated by teachers with various years of knowledge building experience.

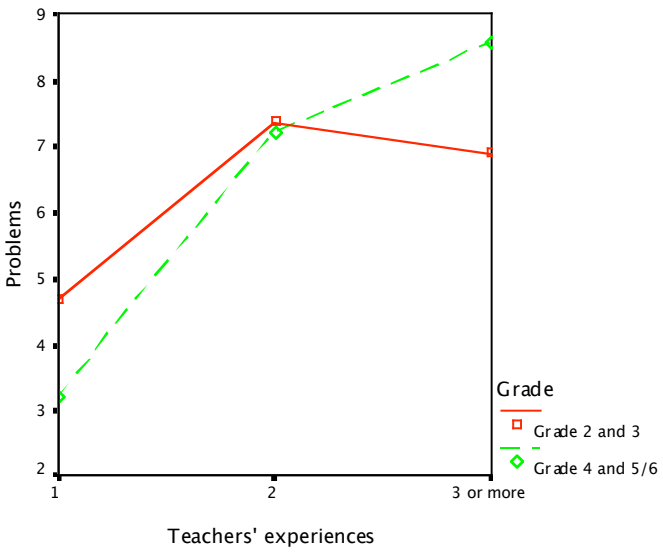

Figure 2. The number of problems worked on by each student in projects facilitated by teachers with various years of knowledge building experience.

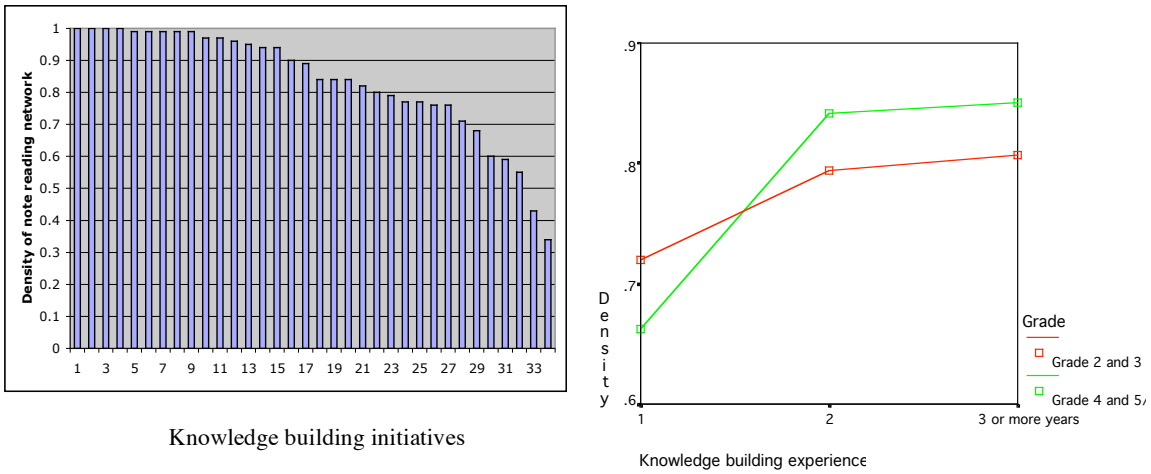

Figure 3. Densities of note reading contacts in initiatives facilitated by teachers with various years of knowledge building experience.

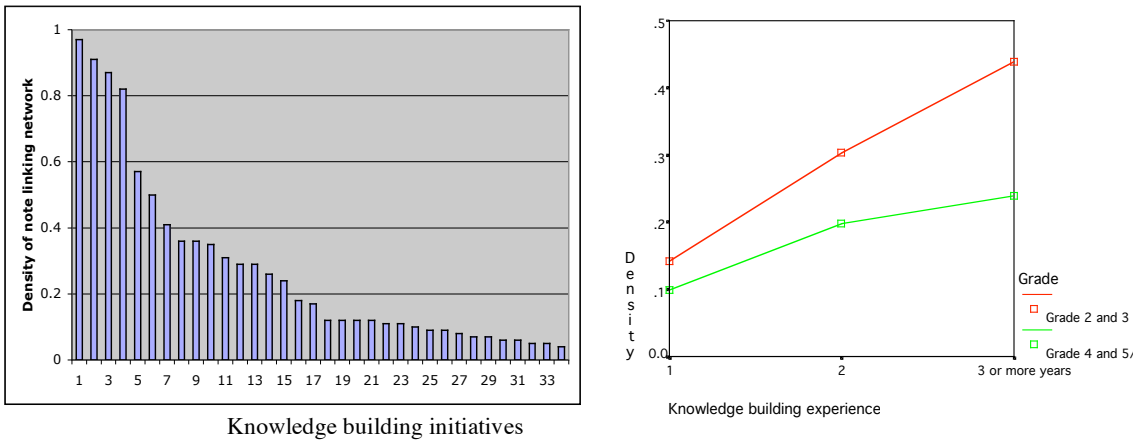

Figure 4. Densities of note linking contacts in knowledge building initiatives facilitated by teachers with various years of experience.

Table 1

The Numbers of Knowledge Building Initiatives Facilitated by Teachers with Different Years of Experience among Students of Different Grades.

	Teachers' experience with knowledge building pedagogy		
	1st year	2nd year	3rd year and later
Lower grades (Grade 2-3)	8	8	3
Upper grades (Grade 4-5/6)	5	3	7

Table 2

Specific Measures of Knowledge Building Practice.

Dimension	Specific measures
Individual contribution	Number of notes created and number of problems worked on by each student.
Community awareness	Density of the note-reading network (who read whose notes) in a community.
Complementary contributions	Density of the note-linking network (who linked to whose notes through building-on, rising-above, or reference citations) in a community.